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## Hydrologic Modeling of the Pecos River Basin Below Red Bluff Reservoir

by

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May 2011

CENTER FOR RESEARCH IN WATER RESOURCES

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**Certifies that this is the approved version of the following thesis:**

# Hydrologic Modeling of the Pecos River Basin below Red Bluff Reservoir

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David Maidment

# Hydrologic Modeling of the Pecos River Basin below Red Bluff Reservoir

by

**Sedat Yalcinkaya, B.S.**

**Thesis**

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of the Requirements

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# Dedication

This work is dedicated to my parents for their continuous support and love, to my sisters for the joy they add to my life, to my relatives and friends who believe in me and motivate me.

## Acknowledgements

I would like to express my appreciation to my advisor Dr. Daene McKinney for his guidance and encouragement. Dr. McKinney provided me the opportunity to work in the water resources planning and management. He let me find my way during my research, while conveying his great experiences to me. I would like to thank Dr. David Maidment for his unique teachings and technical support. It has been a pleasure for me to work with such brilliant and pioneer advisors. Their comments helped me pull this thesis together.

Special thanks to Eusebio Ingol Blanco for his continuous support and expertise in hydrologic modeling. Samuel Sandoval Solis shared his knowledge of the Rio Grande/Bravo Basin. Eusebio and Samuel become great friends. I am grateful for their friendship and support.

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I would like to express my endless gratitude to Republic of Turkey Ministry of National Education for for giving me the opportunity to pursue my graduate study at the University of Texas at Austin.

Finally, I thank my parents and sisters for their continuous support and love. I owe them all my successes.

March 3, 2011

# Abstract

## Hydrologic Modeling of the Pecos River Basin below Red Bluff Reservoir

Sedat Yalcinkaya, M.S.E.

The University of Texas at Austin, 2011

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The segment of the Pecos River that extends from Red Bluff Reservoir until it discharges to the Rio Grande/Bravo near Langtry was studied in this project. Hydrologic behavior of the basin was analyzed between 1981 and 2000, the first ten year period for calibration and the second ten year period for validation by using Water Evaluation and Planning Software (WEAP, SEI, 2006). Simulated streamflows were compared with naturalized streamflows (RJBCO, 2003) at two control points, one in the middle of the basin near Girvin and the other one is at the end of the basin near Langtry. The purpose of the project is to create a valid model for water availability simulations in the Pecos River Basin to be used for future water availability simulations considering climate change effects. The basin was divided into two parts in order to evaluate the results, the upper basin and the entire basin (below Red Bluff reservoir) according to the location of

control gages. Simulated streamflows closely match the naturalized flows at the Girvin station in the upper basin. Although the results at the Langtry station for the entire basin are not as good as Girvin, the model still reproduces streamflows well enough to represent the hydrologic behavior of the basin, especially for the base flow. Considering the complex geological structure of the Pecos River Basin below Red Bluff Reservoir, the results can be considered satisfactory. The model can be used for future water availability predictions in the basin considering climate change effects.

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# Chapter 1: Introduction

Fifty years ago there was less than half of the current number of population on the earth. People were not as wealthy as now and they were not consuming as many calories as today. Negative effects of industrialization on water resources were not as intensive as today. Urbanization was a new concept and depletion of aquifers was not as great as now. In brief, the consumption of water is much more intense today. Unlike 50 years ago, water scarcity is one of the main problems to be faced by many societies and the world today. Almost 1.2 billion people or around one-fifth of the world's population are experiencing water scarcity. Increasing population and the effects of climate change on water resources are expected to aggravate the fresh water crisis all over the world.

In this context, Intergovernmental Panel on Climate Change (IPCC) prepared an individual report just for water resources (UNEP and WMO, 2008); the UN adopted the Millennium Development Goals which include food and water security, and the EU required watershed management plans from its members. All of these actions indicate the seriousness of water stress. In order to manage water resources effectively, planning and management of water resources is inevitable today. Enough water may exist, but it is not available when and where it is needed! The knowledge of the temporal and spatial variability of water is an important aspect in the analysis and evaluation of the water resources in a region. In that sense, hydrologic modeling of the Pecos River Basin below Red Bluff Reservoir in Texas was studied in this project.

Several studies have been carried out regarding the hydrology, geology and ecosystem of the Pecos River Basin; however there is not much research on hydrologic modeling of the basin and assessment of climate change impacts on water resources in the basin. Water availability has become aggravated in the basin, because important increases in agriculture have been experienced for more than 50 years. These facts increased concerns about water resources and brought the following questions to minds: How will water availability change in the next 50 to 100 years considering climate change effects in the basin? How will the changes in water availability affect water allocations in the basin? What precautions will be needed in order to face drought periods?

In this research, an analysis was made using hydrologic modeling of the Pecos River Basin below Red Bluff Reservoir in order to create a model for water availability simulations to be used for future water availability predictions considering climate change effects. The Water Evaluation and Planning (WEAP) modeling software was used for this purpose (SEI, 2006). A 10-year time period from January 1981 to December 1990 was chosen for calibration and another 10-year time period from January 1991 to December 2000 was chosen for validation.

## 1.1 OBJECTIVE

The objectives of this research are:

- Analysis of hydrologic behavior of the Pecos River Basin below Red Bluff Reservoir.
- Creating a model for water availability simulations in the Pecos River Basin to be used for future water availability simulations considering climate change effects.

## 1.2 OVERVIEW OF THESIS

This thesis is presented in five chapters. The first chapter provides an introduction and objectives for this research. A brief description of the basin including geographic, agricultural water use, hydrogeology and ecosystem issues is available in the second chapter. In addition, brief description of the tools utilized and sources of data used in this project are included in Chapter 2. Chapter 3 describes the methodologies used to preprocess input data, model calibration, and statistical computations. In Chapter 4, results for upper and entire basin are presented and analyzed. Conclusions are written in the final chapter.

# Chapter 2: Background

In this chapter, the focus is to provide a description of the study area and a general overview of the tools and data sources that were used in this project. Description of the study area includes agricultural water use, hydrogeology and ecosystem issues within the basin.

## 2.1 THE PECOS RIVER

The Pecos River's headwaters are located north in the State of New Mexico. It flows for 1490 km through the east Texas and discharges into the Rio Grande near Del Rio. It is one of the major tributaries of the Rio Grande. This project considers only the part that extends from Red Bluff Reservoir to Langtry just before the Devils River discharges to the Rio Grande/Bravo. The basin is located geographically between meridians 104°38'59'' and 101°08'7'' west; and between parallels 33°01'11'' and 29°41'26'' north. The basin lies in 2 states and 19 counties, 17 counties in TX and 2 in NM. It has 10 sub-basins and the total area of the basin is 51597 km$^2$. In the analyses, the basin was divided into two parts based on the location of control gages: Upper Basin, from Red Bluff Reservoir to Girvin, and Lower Basin, from Girvin to Langtry. The location of the basin is shown in Figure 1.

The Pecos is located on the eastern boundary of the most mountainous and arid region of Texas, commonly known as the Trans-Pecos. The river flows through a deep gorge from below Sheffield in eastern Pecos County to the river's discharge to the Rio Grande. This gorge constitutes a barrier to transportation and prevents irrigation in this part of the lower Pecos. Elsewhere along the river, increased agricultural development occurred over the last 50 years. Agricultural development has caused increased pumping in the basin and the groundwater levels were fallen. This has changed generally gaining streamflow conditions to generally losing streamflow conditions in many areas. The main crops produced in the Pecos valley include cotton, alfalfa, forage, grain sorghums, vegetables, and fruits, especially cantaloupes. Except during floods, the river is usually a small, shallow, narrow stream with a sluggish current. However, the lower Pecos can become a dangerous river during heavy thunderstorms.

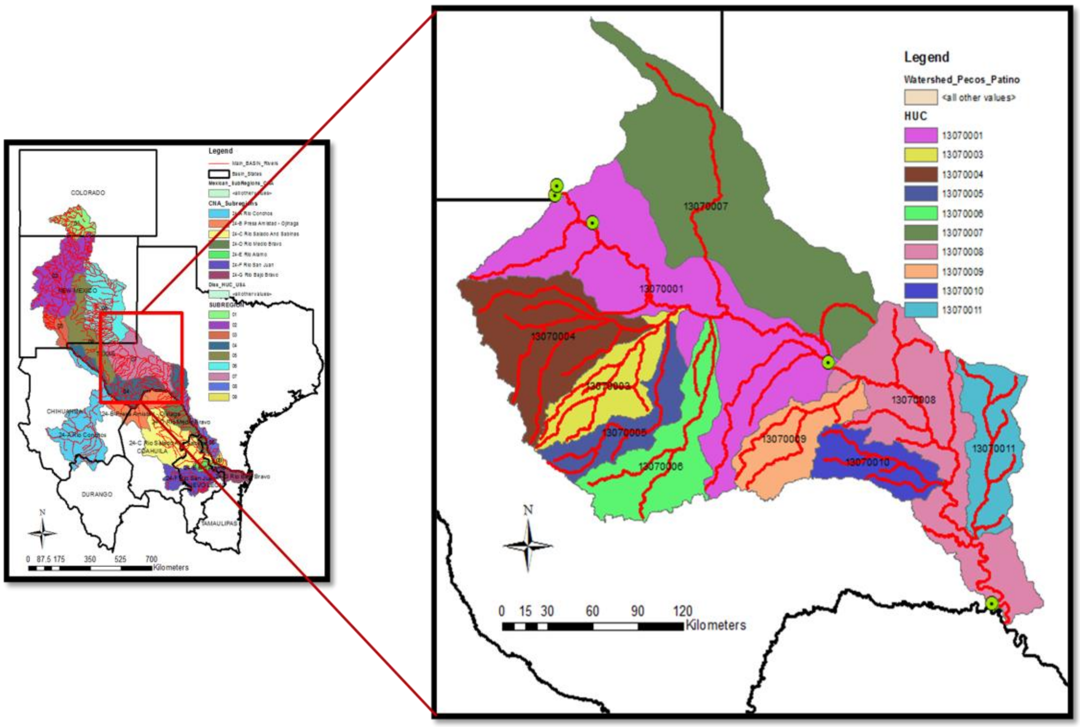


Figure 1: Map of the Study Area

Another important factor affecting the water availability in the basin is the occurrence and density of desert shrubs, phreatophytes (salt cedar). The occurrence of salt cedar in the Pecos River Basin was reported the first time in 1912. They can easily spread by wind, germinate rapidly and impact other vegetation. The rate of spreading between 1915 and 1953 was reported to be 1000 to 1500 acres/year (WAM, RBJCO 2003). These plants are non-beneficial and can cause significant evaporation loss. Some of their effects are decreased flows in the river, disappearing wetlands and decreases in wildlife habitat. Water consumption by salt cedar is highest in July and August and lowest in December and January. According to a 1940 study (King and Bawazir, 2000), water consumption by vegetation along the Pecos River from Red Bluff Reservoir to Girvin was assessed at 5.9 to 6 acre-feet per acre per year. "…Riparian evapotranspiration is one of the largest loss components in the Middle Rio Grande hydrologic budget and one of the least understood. Much uncertainty exists as to the consumptive use of riparian vegetation such as salt cedar and cottonwood," is stated as a conclusion of evapotranspiration studies of riparian vegetation in the Middle Rio Grande Basin (King and Bawazir, 2000). Salt Cedar have become more prevalent in many areas over the last 2 to 3 decades. Some salt cedar eradication programs are being applied in order to reduce their occurrence and so decrease the water consumption by these plants.

Pecos River Basin has a complex geological structure. It lays on two major aquifers Edwards-Trinity (Plateau) Aquifer (ETPA) and Cenozoic Pecos Alluvium Aquifer (CPAA), and four minor aquifers: Dockum, Capitan Reef Complex, Rustler and Igneous. Major and Minor Aquifers of the Pecos River Basin are shown in Figure 2 and Figure 3 respectively. ETPA and CPAA separate the basin in two different hydro geological areas at Girvin and that causes different characteristics between the upper and lower basin. While ETPA is the dominant aquifer at the lower basin, CPAA is the dominant aquifer in the upper basin. Val Verde, Crockett and Terrell counties are overlain by water bearing Quaternary alluvium deposits. Val Verde County is the major groundwater discharge area of ETPA. Winkler, Ward and Crane counties are the major areas for recharge from precipitation. Heavy pumping occurs in Pecos and Reeves counties for irrigation purposes. A large percentage of recharge to CPAA comes from irrigation return flows.

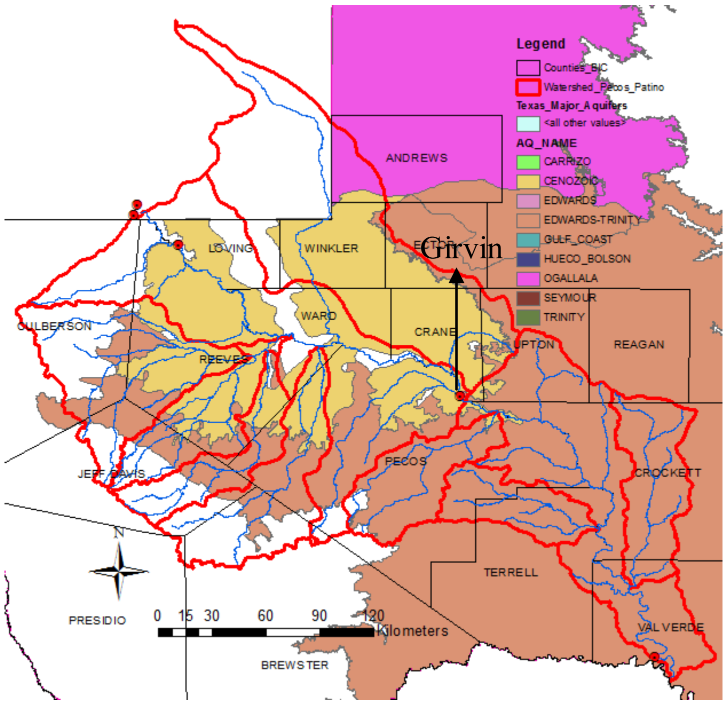


Figure 2: Major Aquifers of the Pecos River Basin

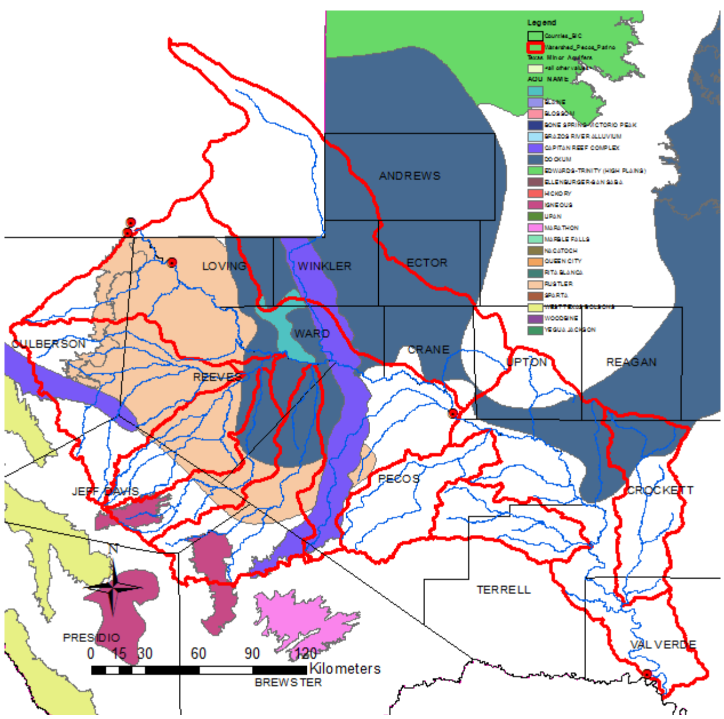


Figure 3: Minor Aquifers of the Pecos River Basin

## 2.2 ANALYTICAL TOOLS

This section outlines the two analytical tools, ArcGIS and WEAP that were used in this research.

### 2.2.1 ArcGIS with Arc Hydro Data Model

ArcGIS was developed by Environmental Systems Research Institute, Inc. (ESRI) in California. This program organizes and analyzes geographic information to support planners and managers in well-informed decision making (ESRI).

The Arc Hydro data model was developed by the Center for Research in Water Resources (CRWR) at the University of Texas at Austin and ESRI. It is a data model and a set of tools to manage spatial and temporal data related to water resources in the ArcGIS (Maidment, 2002). Arc Hydro enables the storage and processing geospatial and temporal hydrologic data that are necessary for hydrologic modeling (see Figure 4).

ArcGIS with the Arc Hydro Data Model was used for geospatial representation of the Pecos River Basin and pre-processing the data in this project.

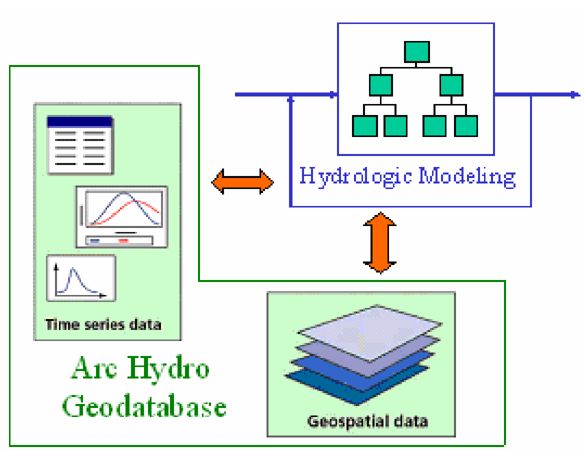


Figure 4: Relationship between Arc Hydro Geodatabase and Hydrologic Modeling. Source: Maidment (2002)

### 2.2.2 Water Evaluating and Planning System

Water Evaluation and Planning (WEAP) software, developed by the Stockholm Environmental Institute (SEI, 1988), was used for streamflow simulations in this project because of its integrated structure. What makes WEAP software distinctive from other modeling software and the reason why it was chosen for this project is that it has an integrated approach to simulate water balance, generate scenarios and analyze different policies.

WEAP is based on the fundamental principles of mass balance. It can be used to simulate rainfall runoff, baseflow, and groundwater recharge from precipitation; sectoral demand analysis; water conservation; water rights and allocation priorities, reservoir operations; hydropower generation; pollution tracking and water quality; vulnerability assessment; and ecosystem requirements (SEI). It can also investigate cost-benefit analysis. WEAP can be applied to small systems such as a single watershed or bigger systems such as complex transboundary river basin systems. Only the hydrology feature of WEAP was used for this project in order to simulate streamflows from precipitation.

## 2.3 Data Sources

This section outlines the sources of data and data types utilized in this research. In order to describe the hydrologic behavior of the basin, WEAP software requires detailed hydrologic and climatic parameters.

### 2.3.1 Required Parameters

Since the Soil Moisture Method was used to simulate streamflows in WEAP, the input parameters in Table 1 are required. The Soil Moisture Method is presented under the Methodology Chapter. Because the naturalized flow data which was compared with the simulated streamflow is for a monthly time period, some of the required parameters are also needed to be in terms of a monthly time period. In addition, all input parameters should be represented for each catchment in the basin to be able to be processed by WEAP. All required input parameters are presented in Table 1 along with the sensitivities which resulted from an early study (Jantzen et al., 2006).

| **Parameter** | **Units** | **Time Variation** | **Resolution** | **Sensitivity** |
|---|---|---|---|---|
| **Land Use** | | | | |
| Area | sq km | no variation | Catchment | High |
| Deep Water Capacity | mm | no variation | Catchment | High |
| Deep Conductivity | mm/month | Monthly | Catchment | Moderate |
| Initial Z2 | % | no variation | Catchment | No Influence |
| Soil Water Capacity | mm | no variation | Soil | Moderate |
| Root Zone Conductivity | mm/month | Monthly | Soil | Moderate |
| Preferred flow Direction | no unit | no variation | Soil | Moderate |
| Initial Z1 | % | no variation | Soil | No Influence |
| Crop Coefficient, Kc | no unit | Monthly | Land Use | High |
| Leaf Area Index | no unit | Monthly | Land Use | High |
| **Climate** | | | | |
| Precipitation | mm/month | Monthly | Catchment | High |
| Temperature | C | Monthly | Catchment | Moderate |
| Wind | m/s | Monthly | Catchment | Low |
| Humidity | % | Monthly | Catchment | Low |
| Melting Point | C | no variation | Catchment | Not Evaluated |
| Freezing Point | C | no variation | Catchment | Not Evaluated |
| Latitude | degree | no variation | Catchment | Not Evaluated |
| Initial Snow | mm | no variation | Catchment | Not Evaluated |

Table 1: Required Input Parameters.

### 2.3.2 The Rio Grande/Bravo Geodatabase

The geodatabase, which was developed for the whole Rio Grande/Bravo basin by Center for Water Resources (CRWR) at the University of Texas at Austin in cooperation with the National Water Commission of Mexico (Patino, 2005), was used for this project. Spatial and temporal information from both Mexican and U.S. agencies were stored in this geodatabase. Gaging stations with related time series data, climatic stations, watersheds, streams and water bodies are some of the stored data in this geodatabase in addition to information about reservoirs and groundwater. The geodatabase is in the Geographic Coordinate System corresponding to GCS_North_American_1983, while the datum is the NAD Datum 1983. All the data obtained from the CRWR Geodatabase, ftp://ftp.crwr.utexas.edu/pub/outgoing/PATINOC/RioGrandeInfo/, are listed in Table 2.

| Shapefile Name in the Rio Grande/Bravo Geodatabase | Description |
|---|---|
| CoutiesBIC | Counties of the basin in Texas |
| Basin_Sates | States of the basin |
| USA_HUC8Dig_100K | Watersheds on the U.S. side |
| Main_AmericanRivers | Main rivers on the U.S. side |
| TCEQ_NaturalizedFlows | TCEQ naturalized flow gage points |
| Texas_Minor_ Aquifers | Minor aquifers of Texas |
| Texas_Major_ Aquifers | Major aquifers of Texas |
| WaterBody | Water bodies in the basin |

Table 2: Shapefiles acquired from the CRWR Geodatabase.

NHDPlus data, a project of the U.S. EPA (NHDPlus, 2006), was also considered during the geodatabase selection process. When the two datasets, NHDPlus and the CRWR Geodatabase were compared, some differences were found. Since the CRWR Geodatabase was developed only for the Rio Grande/Bravo Basin with some distinctive techniques such as raster regionalization (Patino, 2005) and it is the geodatabase of the Physical Assessment Project, it was chosen for this project. Differences between the two geodatabase are presented in Figure 5 and Figure 6. While total area is the same in the two datasets, significant differences are present in some sub-basins. In addition, the CRWR data set represents the entire basin in 10 sub-basins, where as NHDPlus represents the entire basin in 11 sub-basins.

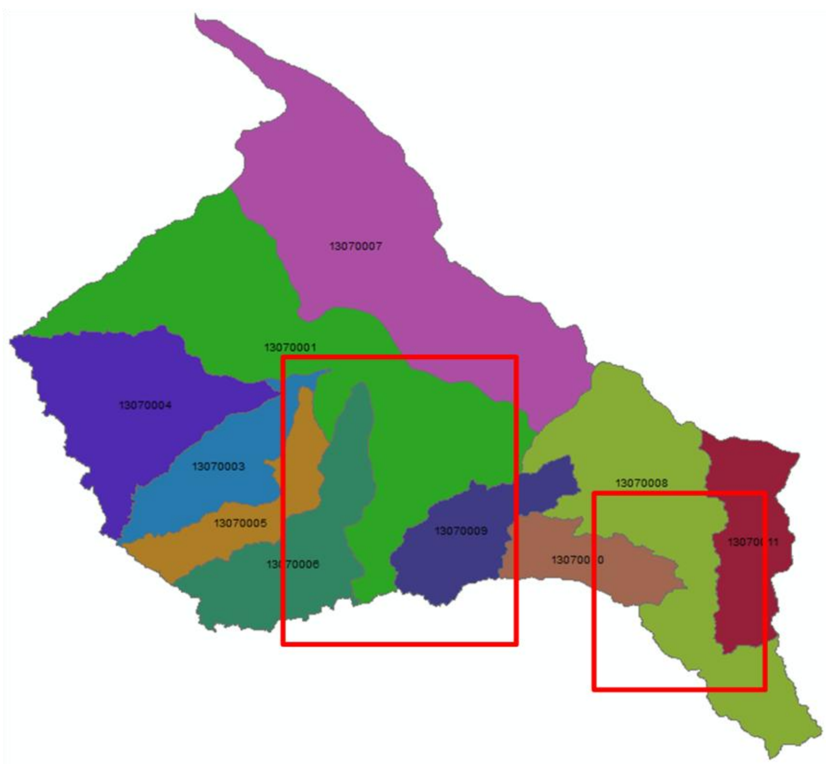


Figure 5: The CRWR Sub-basins.

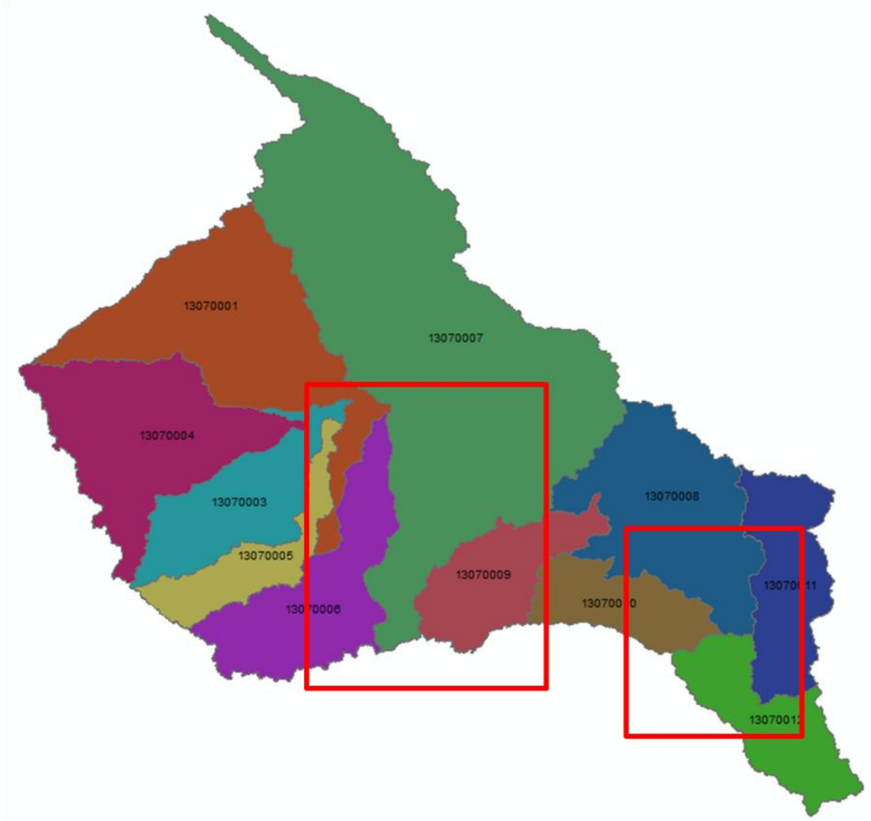


Figure 6: NHDPlus Sub-basins.

### 2.3.3 Naturalized Streamflow Data

Naturalized streamflow data for the Rio Grande/Bravo Basin was prepared by the R.J. Brandes Company (RJBCO, 2003) for the Texas Commission on Environmental Quality (TCEQ). The TCEQ Water Availability Model (WAM) was used to predict the naturalized streamflow data. The naturalized streamflow data for the 61-year period from January 1940 through December 2000 was prepared for relevant gaging stations, where streamflow gages currently exist or previously existed, in the Rio Grande/Bravo Basin. There are forty-three gages in total, 23 of them are located in the U.S., and 20 in Mexico. Five of these gages are related to this project's study area. These gages are listed in Table 3 and shown in Figure 7.

| Gage Location | NO | Drainage Area, km2 | X_COORD | Y_COORD |
|---|---|---|---|---|
| Delaware R nr Red Bluff, NM | GT5000 | 50586.734 | -104.03903 | 32.07545 |
| Pecos R at Red Bluff, NM | GT4000 | 2029.63 | -104.05427 | 32.02319 |
| Pecos R nr Orla, TX | GT3000 | 54697.855 | -103.83169 | 31.87279 |
| Pecos R nr Girvin, TX | GT2000 | 85174.414 | -102.41764 | 31.11333 |
| Pecos R nr Langtry, TX | GT1000 | 103576.008 | -101.44261 | 29.80257 |

Table 3: Pecos River Gage Stations and Drainage Areas

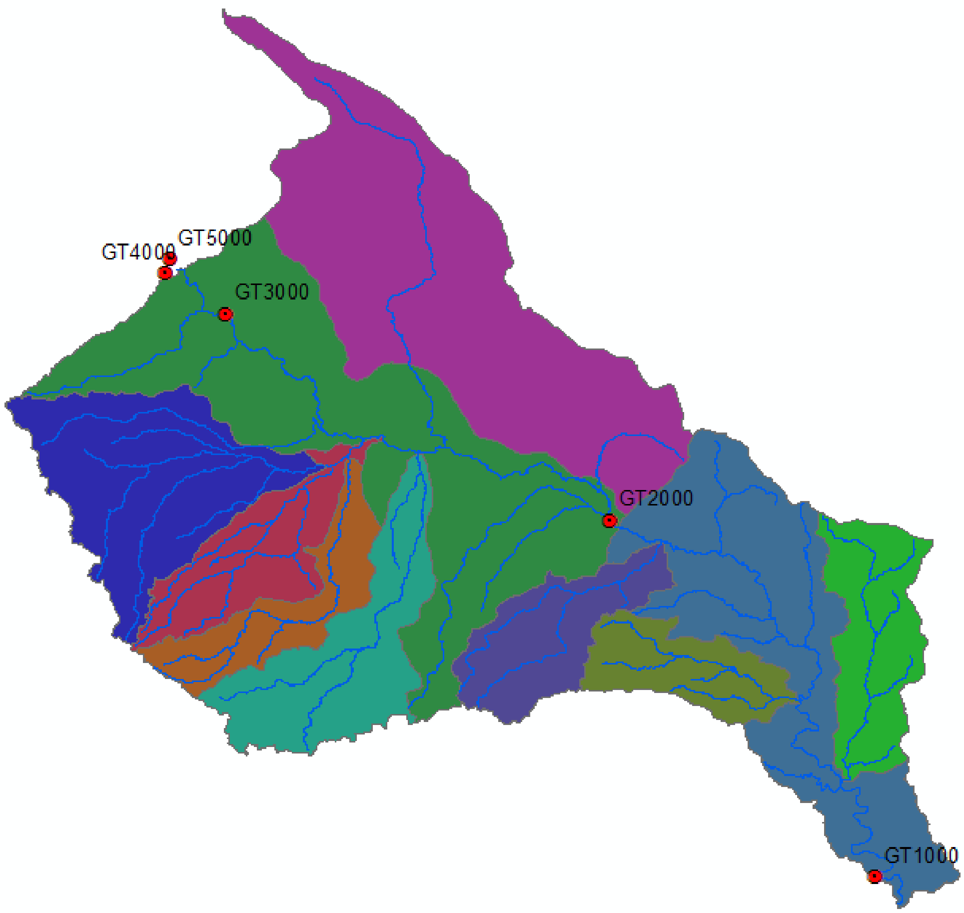


Figure 7: Location of Gage Stations (red circles) in the Pecos River Basin

The streamflow naturalization process involves extracting the anthropogenic effects from historical streamflow records. Anthropogenic effects include diversions of surface water, discharges of municipal and industrial wastewater, irrigation return flows and spring flow, and reservoir depletions due to storage and evaporation. For detailed information about streamflow naturalization, the Naturalized Streamflow Data Final Report (RJBCO, 2003) should be reviewed. The following equation was used to calculate the naturalized streamflows for each control gage from up to down in the Rio Grande/Bravo Basin (RJBCO, 2003) and it simply describes the streamflow naturalization process:

| | | |
|---|---|---|
| Naturalized Streamflow = | | Historical Gaged Streamflow |
| | + | Historical Upstream Diversions |
| | – | Historical Upstream Return Flows |
| | + | Historical Changes in Upstream Reservoir Storage |
| | + | Historical Upstream Reservoir Evaporation Loss |
| | - | Historical Upstream Miscellaneous Adjustments (e.g. spring flows) |
| | + | Channel Losses |

Since streamflow naturalization is a complex process, depends on many assumptions and requires certain data, it can be difficult to get good results. There are some special cases indicated for the Pecos River Basin in the WAM report. Naturalized streamflow values resulted in negative flow for certain months at the Pecos River near the Girvin gage more than any other gage. Negative values were handled by setting them to zero, because it cannot happen physically. Another difficulty in predicting naturalized streamflow in the Pecos River Basin is that there are no storage records at Balmorhea Reservoir which is one of the two reservoirs in the basin. In addition, only San Solomon

Springs has a fairly complete discharge record amongst two other springs, Phantom Lake and Giffin, which are located in Reeves and Jeff Davis counties. The maximum channel loss rate in the Rio Grande/Bravo Basin also occurs in the Pecos River. This is a 48% channel loss rate including seepage, evaporation and salt cedar loss rates and occurs in the reach from Orla to Girvin, in addition, a 30% channel loss rate occurs in the reach from Girvin to Langtry. Most of these losses, 44% and 19%, respectively, occur due to salt cedar.

### 2.3.4 Climate Data

Three different climate data were analyzed for this project: NARR, TWDB and NCDC.

#### *2.3.4.1 NARR Data*

North American Regional Reanalysis (NARR) dataset is developed by National Climatic Data Center (NCEP, 2005). It is an advanced long-term re-analysis of main meteorological components. The dataset contains 32-km spatial and 3-hour analyses of North America, adjacent oceans and land masses from October 1978 to present (NCEP, 2004).

Since monthly streamflow simulation between 1981 to 2000 years was planned for this project and the NARR dataset has the highest resolution data for this time period, it was chosen for this project. In addition, NARR precipitation data compared with TWBD precipitation data in order to control whether NARR provides a good representation of precipitation or not. Both data were correlated and they matched with a high agreement, $R^2$=0.97.

Precipitation, surface temperature, relative humidity at 2m height above the ground, vertical and horizontal components of wind data were downloaded from the

NARR website, http://nomads.ncdc.noaa.gov/data.php?name=access#narr_datasets. The scale of the data is between 45.5 and 0.75 longitudes, and between -145.5 and -2.3 latitudes in decimal degrees. Default values were used for other climate parameters of melting point, freezing point and initial snow. Data are presented in 3-hour periods and 3-hour averaged monthly periods. There are also, two different files for each analysis time, A and B. The A file contains more data than B. The NARRMON_A data model, 3-hour averaged monthly file, was chosen for this project.

#### *2.3.4.2 TWBD Data*

The Texas Water Development Board (TWDB) developed an evaporation and precipitation dataset for Texas using data from National Weather Service and TWDB. Evaporation data is available from 1954 through 2007, while precipitation data are available from 1940 through 2007. The data are presented in one degree quadrangles in Texas. The evaporation component of this dataset was used in the WAM for the Rio Grande/Bravo Basin in order to calculate evaporation losses. Only the precipitation component was used in this project to compare with NARR data. Precipitation data for the No. 504, 505, 603, 604, 605, 606, 703, 704, 705, 706, and 806 quadrangles were downloaded from TWBD's website, http://midgewater.twdb.state.tx.us/Evaporation/evap.html. Data representation in one degree quadrangles is presented in Figure 8.

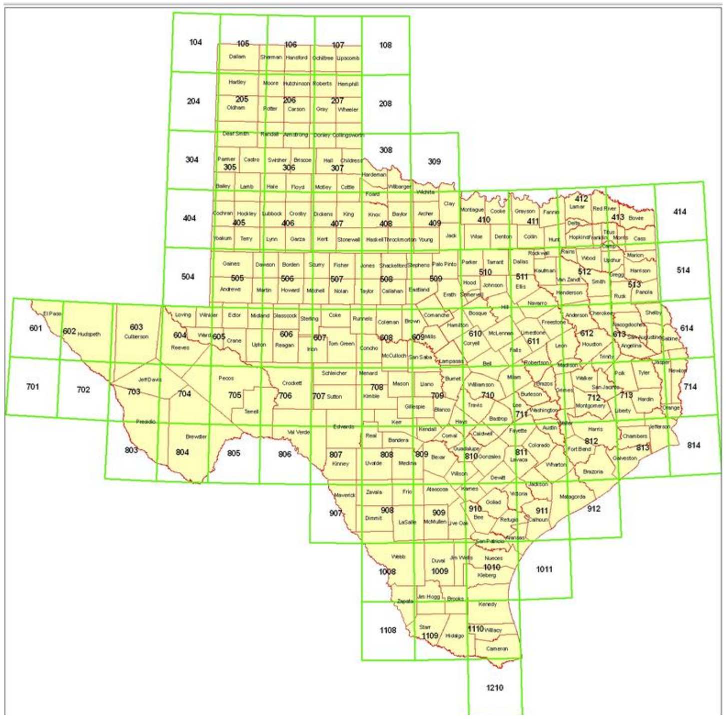


Figure 8: TWDB data representation in one degree quadrangles in Texas.

### *2.3.4.3 NCDC Data*

The National Climatic Data Center also has several climatic stations in the basin. These stations are shown in Figure 9. Since these stations directly measure climatic parameters at one point, they are represented as point source data. NCDC data couldn't be used in this project, because there are not enough stations with complete data for the required time period, from January 1981 through December 2000. Station names and coordinates are presented in Appendix A.

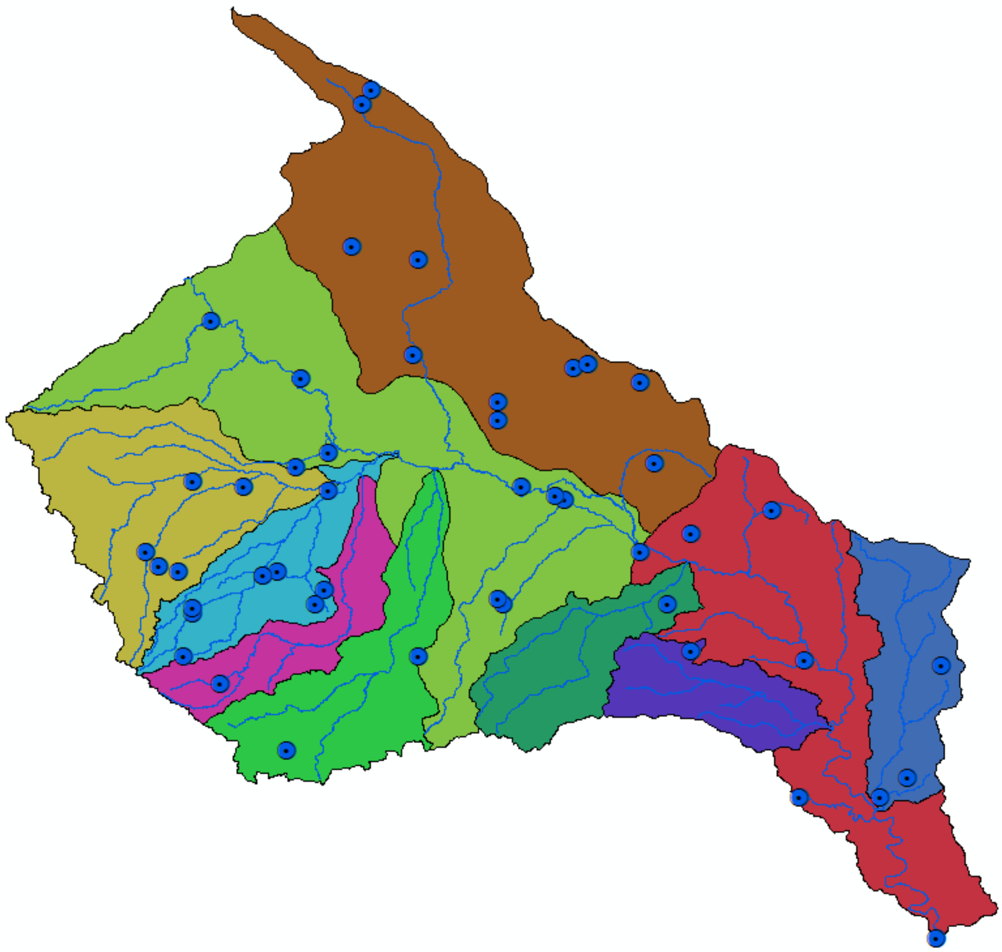

Figure 9: Location of NCDC stations (blue circles) in the Pecos River Basin

### 2.3.5 Soil Data

Conductivity, initial water storage, water capacity and preferred flow direction are the required soil parameters for the WEAP soil moisture method. Since initial water storage and preferred flow direction data are not available, they were assumed. Only conductivity and water capacity data were searched from available soil data sources.

During this project, a study was made on soil data sources for the Pecos River Basin. There are available four soil databases. FAO-UNESCO Soil Map of the World is developed by FAO (FAO, 2007). The Soil Conservation Service (SCS) of the U.S.

Department of Agriculture (USDA) also developed three digital soil geographic databases with different detailed levels of soil information intensities for the U.S. which are Soil Survey Geographic Data Base (SSURGO), State Soil Geographic Data Base (STATSGO) and National Soil Geographic Data Base (NATSGO). All these data bases were investigated to get the required soil data for this project.

FAO-UNESCO Soil Map of the World is the least detailed level of the data bases and it is suitable for large scale uses such as continental or national. It is represented at the 1:5,000,000 scale in vector format and 5 arc minutes in raster format. Its latest version was completed in 2007 and it is available at http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116 in different formats. The disadvantage of this data base is that it does not provide conductivity and water capacity information. It contains soil classification information, so conductivity and water capacity have to be checked according to soil classes. FAO-UNESCO Soil Map of the World is shown in Figure 10.

The NATSGO data base is another large scale data base with a scale of 1:7,500,000. It is used mainly for national, regional and multistate scale purposes. It can be a good data base for the purpose of this project; however it is still under development.

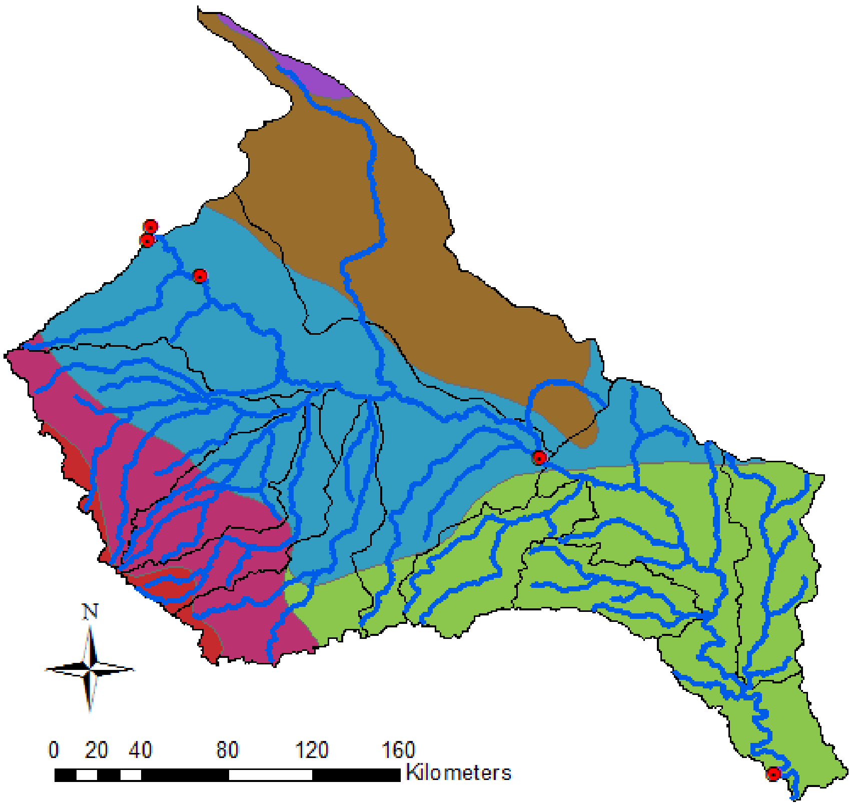


Figure 10: FAO-UNESCO Soil Map of the World for the Pecos River Basin

The STATSGO data base is more detailed than the NATSGO and FAO-UNESCO Soil Map of the World data bases and less detailed than the SSURGO data base. It is primarily used for river basin, state and multicounty scale purposes (NRCS, 2006). It is represented at the 1:250,000 scale in vector format. It is available at http://datagateway.nrcs.usda.gov/. The STATSGO data base is shown in Figure 11.

The SSURGO data base is the most detailed level of information. It is primarily used for farm and ranch scale purposes. The SSURGO data base is represented at the 1:12,000 to 1:31,680 scales in vector format. The SSRUGO map for the basin has 18265 polygons, while the STATSGO map has only 149 polygons. It is also available at http://datagateway.nrcs.usda.gov/. The SSURGO data base is shown in Figure 12.

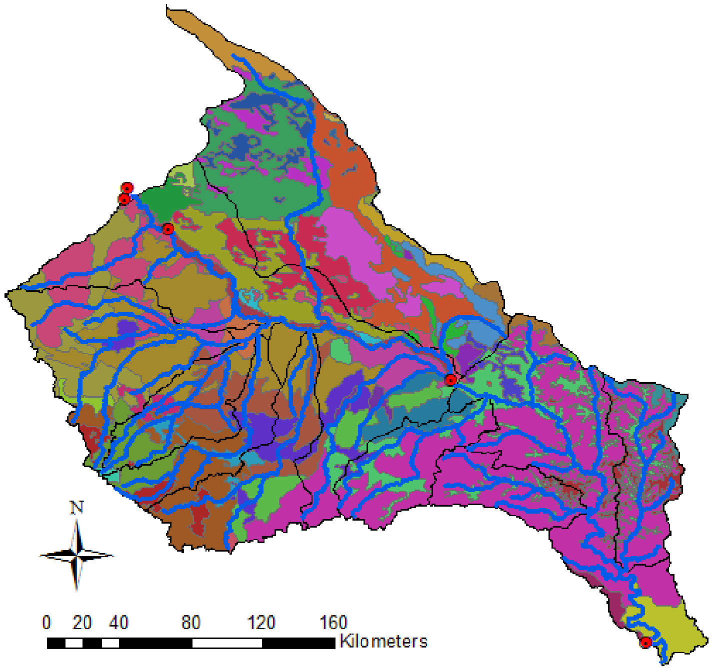


Figure 11: STATSGO Soil Map for the Pecos River Basin

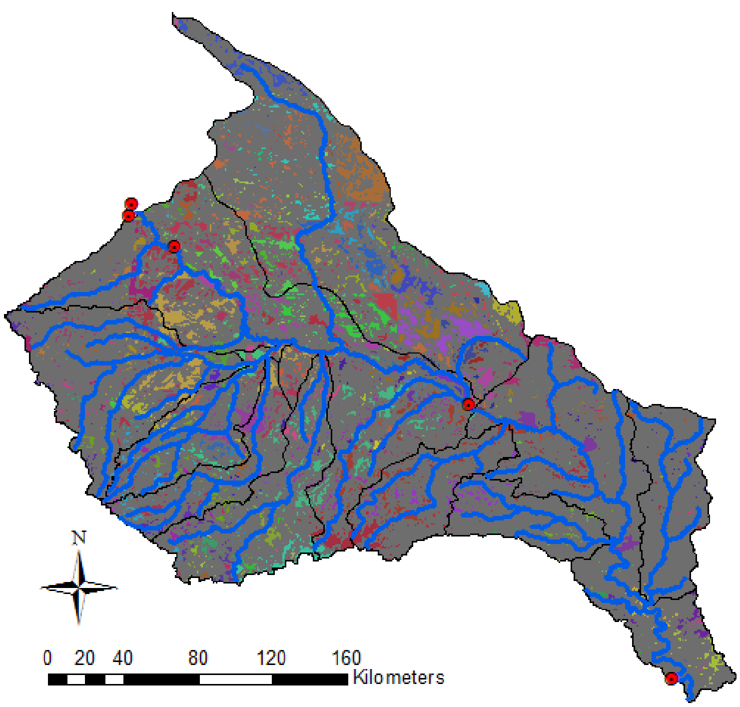


Figure 12: SSURGO Soil Map for the Pecos River Basin

The STATSGO and SSURGO databases have the required data. However, their attribute data are stored in a MS Access data base template and they are not user friendly. In addition, it is almost impossible to calculate average values of the required soil parameters for each sub-watershed because of their complex and detailed data representation structure. For example, each polygon represents a mapunit and each mapunit represents different percentages of components. Every mapunit has a unique color, so components in a mapunit cannot be distinguished. STATSGO mapunits could have up to 21 different components with different. Each component has unique soil properties and up to 5 layers with different thicknesses. This relationship is shown in Figure 13.

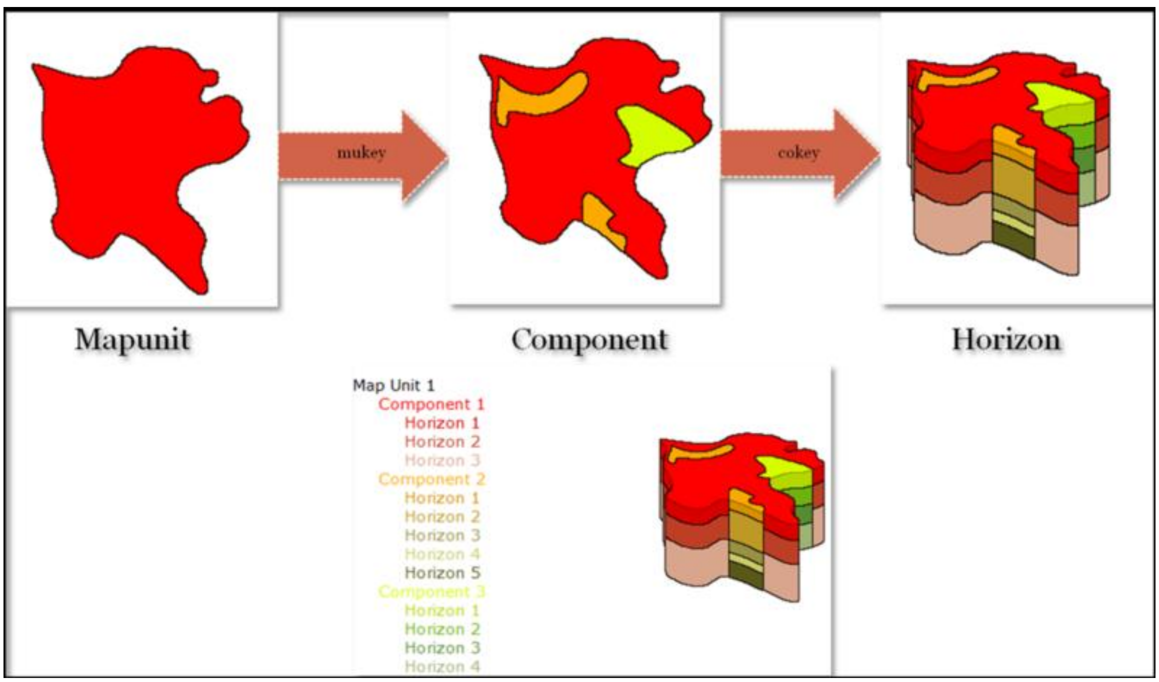


Figure 13: Data Representation Relationship in STATSGO and SSURGO

Because of these difficulties, a derived version of these data bases is used for this project. A data set was derived from STATSGO and 5 minute FAO data by National Oceanic and Atmospheric Administration (NOAA) within the scope of the North American Land Data Assimilation System (NLDAS, 2008) that will lead to more accurate reanalysis and forecast simulations by numerical weather prediction (NWP) models (NOAA). This dataset includes soil hydraulic properties such as conductivity and water capacity. The dataset has 11 layers and 16 texture classes which are presented in Appendix B. Soil hydraulic properties data set based on Rawls et al. (1991) was used for this project and it is available at http://www.emc.ncep.noaa.gov/mmb/nldas/LDAS8th/soils/LDASsoils.shtml.

### 2.3.6 Land Use Data

Crop coefficient (Kc) and Runoff Resistance Factor are the required land use parameters for the WEAP soil moisture method.

Crop coefficient data were obtained from two different sources: National Oceanic and Atmospheric Administration (NOAA) and the Multi-Resolution Land Characteristics (MRLC) Consortium. NOAA developed a 1/8-degree vegetation data set by using the University of Maryland's 1km Global Land Cover data for use in the NLDAS project. It has 14 vegetation types and the data is stored in ASCII files. It is available at http://www.emc.ncep.noaa.gov/mmb/nldas/LDAS8th/EROSveg2/LDASvegetation2.shtml. The list of UMD vegetation types are presented in Appendix C. The MLRC Consortium was constituted by a group of federal agencies to develop National Land Cover Database (NLCD). NLCD data is more detailed and has more vegetation classes. NLCD vegetation classes are presented in Appendix D. It is available at http://datagateway.nrcs.usda.gov/. The NLCD land cover map for the Pecos River Basin is shown in Figure 14. Both the NOAA and MLRC data are used to calculate and compare Kc values.

Leaf Area Index (LAI) controls the surface runoff response and it varies with land cover. NOAA developed a 1/8-degree vegetation greenness fraction dataset by re-gridding the global dataset of the NCEP's Eta fixed dataset. The twelve monthly greenness fraction fields are available in ASCII format at http://www.emc.ncep.noaa.gov/mmb/nldas/LDAS8th/green/LDASgreen.shtml.

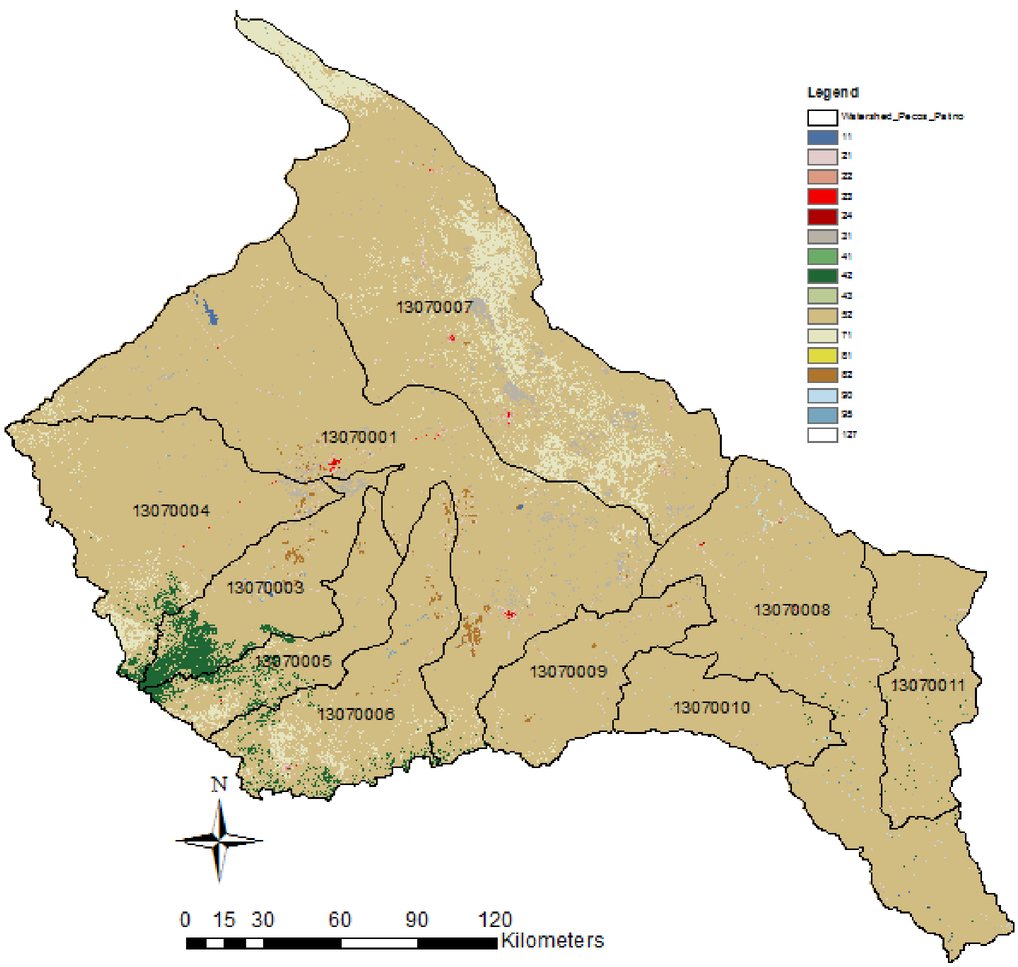


Figure 14: NLCD Land Cover Map for the Pecos River Basin

# Chapter 3: Methodology

In this chapter, the methodology used for data preprocessing, calibration and statistical computations are presented.

## 3.1 Soil Moisture Method

By the time this project was undertaken, WEAP was able to support three hydrologic modeling methods: Rain Runoff (FAO), Irrigation Demands Only (FAO), and Rainfall Runoff (Soil Moisture Method). Later, another method MABIA was also added to WEAP. The Rainfall Runoff (Soil Moisture) Method was chosen for this project, since it provides the most comprehensive calculation. The Soil Moisture Method can analyze the effects of land use, soil type and climate on hydrological process better than the other two methods. However, it requires more input data and makes the calibration process more complex.

The Soil Moisture Method has a one-dimensional and two soil layer (bucket) structure (see Figure 15). The first layer represents interflow and the water in this layer is retained near the ground surface. The second layer extends deeper and represents base flow and groundwater recharge. The Soil Moisture Method is able to simulate the behavior of evapotranspiration, surface runoff, interflow, base flow, and deep percolation for each sub-watershed as well as the entire basin. The method considers the water holding capacity of the layers and the water movement between the layers. The basic mathematical expressions presented below were taken from SEI (2007).

$$\overbrace{Rd_j \frac{dz_{1,j}}{dt}}^{\text{Relative storage in the root zone}} = \overbrace{P_e(t)}^{\text{Effective Precipitation}} - \overbrace{PET(t)k_{c,j}(t)\left(\frac{5z_{1,j}-2z_{1j}^2}{3}\right)}^{\text{Evapotranspiration}} - \overbrace{P_e(t)z_{1,j}^{RRF_j}}^{\text{Surface runoff}} - \overbrace{f_j k_{s,j} z_{1j}^2}^{\text{Interflow}}$$

$$- \underbrace{(1-f_j)k_{s,j}z_{1j}^2}_{\text{Deep Percolation}} \qquad (1)$$

(1)

| | |
|---|---|
| $z_{1,j}$ | Relative soil water storage, a fraction of the total effective water storage in the root zone layer in area *j* |
| $Rd_j$ | Soil water holding capacity of area *j* |
| $P_e$ | Effective precipitation [L] |
| $PET(t)$ | PET is the Penman-Monteith reference crop potential evapotranspiration [L/T] |
| $k_{c,j}$ | Crop coefficient for area *j* |
| $RRF_j$ | Runoff Resistance Factor for area *j* that depends of the land cover. Higher values of this factor result in higher evaporation and less runoff from the basin. |
| $P_e(t)z_{1,j}^{RRF_j}$ | Surface runoff |
| $f_j k_{s,j} z_{1j}^2$ | Interflow from the first soil layer for area j |
| $f_j$ | Partitioning coefficient related to the land cover type, soil, and topography for area *j*, that divides flow into horizontal $f_j$ and vertical (1-$f_j$) flows |
| $k_{s,j}$ | Saturated hydraulic conductivity of the root zone layer of area *j* |
| $(1-f_j)k_{s,j}z_{1j}^2$ | Percolation from first layer to second layer |

The storage change in the second layer (bucket) is calculated by the following expression:

$$\overbrace{S_{max}\frac{dz_2}{dt}}^{\text{Relative storage in the deep zone}} = \overbrace{\left[\sum_{j=1}^{N}(1-f_j)k_{s,j}z_{1,j}^2\right]}^{\text{Deep percolation from the root zone}} - \overbrace{k_{s2}z_2^2}^{\text{Base flow}} \qquad (2)$$

(2)

| | |
|---|---|
| $S_{max}$ | Deep percolation from the upper layer storage |
| $k_{s2}$ | Saturated hydraulic conductivity of the second layer |
| $z_{2,j}$ | Relative soil water storage, a fraction of the total effective water storage in the second layer in area *j* |

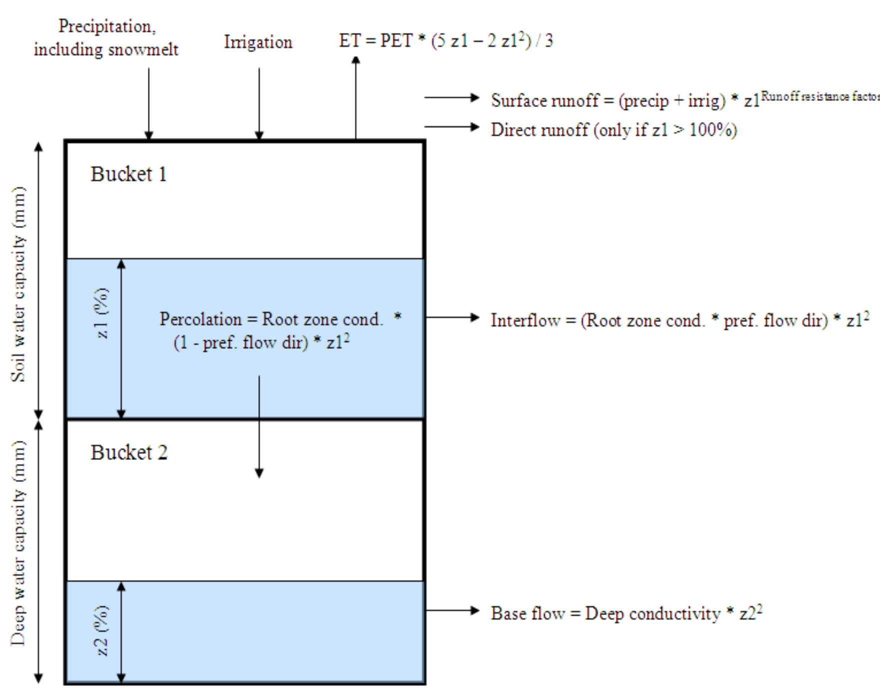


Figure 15: Conceptual Diagram and Equations Incorporated in the Soil Moisture Method, SEI

## 3.2 Data Preprocessing

This section outlines the required input data preparation for WEAP simulation. Input data were also examined before being used in the WEAP hydrology model.

### 3.2.1 Schematic Display of the Basin in WEAP

WEAP allows catchments and rivers in the CRWR geodatabase to be imported as a background map. However, they have to be projected from the CRWR geodatabase coordinate system, GCS_North_American_1983 coordinates and NAD_1983_Albers projection, to the WEAP coordinate system, GCS_WGS_1984 coordinates with a degree bound frame (Patino and McKinney, 2005). Then, these data have to be converted to shapefiles in order to import them as vector layers in WEAP. After this, catchments and rivers can be seen only visually in WEAP, they cannot be represented as input to WEAP.

In order to represent the river data as an input in WEAP, the rivers are drawn in WEAP by tracing over the schematic view. There are inaccuracies between the drawn river reaches and the imported CRWR Rivers. Accuracy is important, especially for reach length data, when simulating the groundwater and surface water interactions. Since groundwater wasn't simulated in this project, only a simple representation of the river is needed. Tributaries which discharge to the main river were named according to the catchment number they flow through. For example, Tributary 6 flows through catchment no C13070006 and discharges to the main river. River reaches drawn in WEAP and those imported from CRWR, re shown in Figure 16.

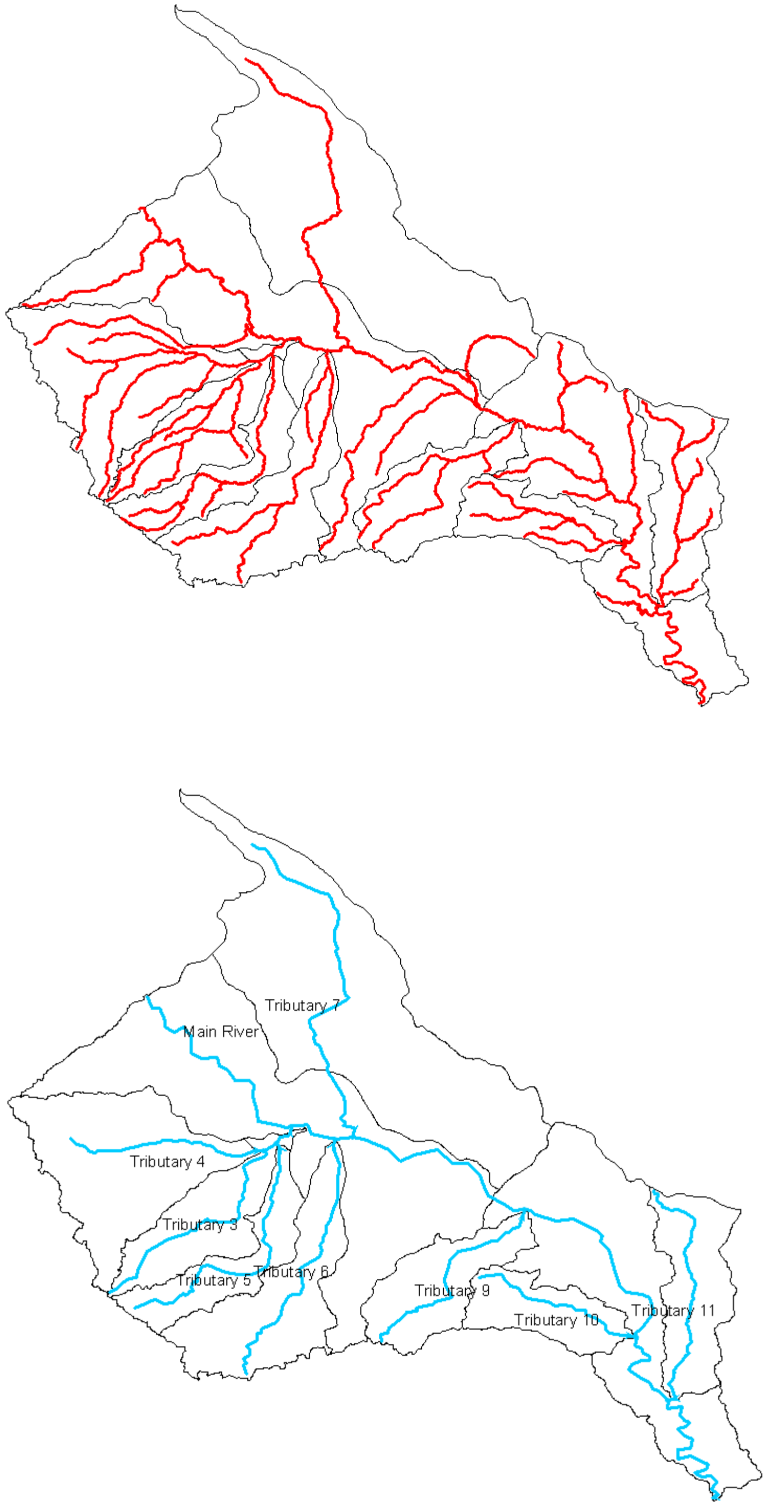


Figure 16: CRWR Rivers (red lines) and WEAP Rivers (blue lines)

The same rule is valid for catchments and streamflow gauges as well. Each catchment is represented by a green dot and named according to the CRWR geodatabase Hydrologic Unit Code (HUC8) numbers. For example, a sub-watershed with the HUC number 13070001 was named as C13070001. GT2000 and GT1000 TCEQ streamflow gages are represented with blue dots.

After the river system and catchments were represented in WEAP, their connectivity was provided. Conceptual connection of the catchment runoff to the appropriate river reach was made by dashed blue lines. A complete schematic view of the Pecos River Basin is shown in Figure 17. After the system representation in WEAP, the required data can be entered in the model.

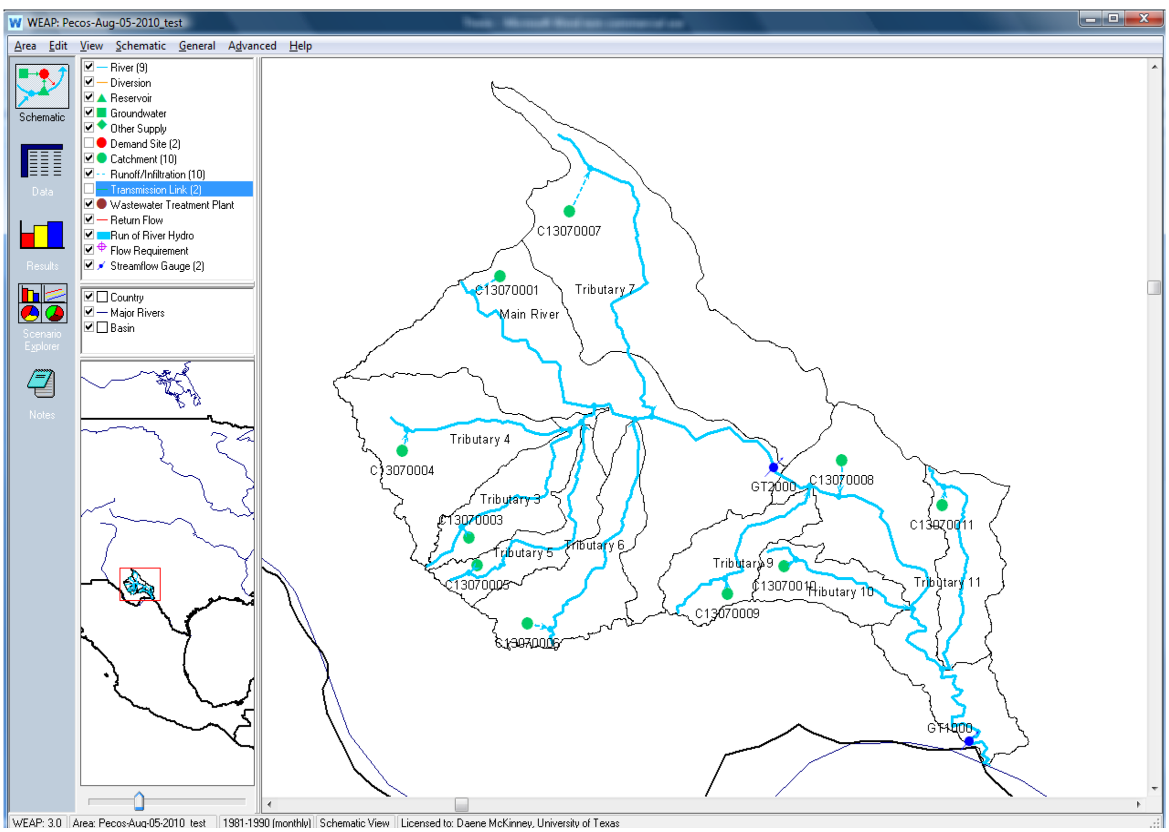


Figure 17: Schematic View of the Pecos River Basin in WEAP

### 3.2.2 Catchment Area

Catchment area is one of the fundamental parameters for hydrologic modeling. Catchment area data was obtained from the CRWR geodatabase and manually entered in WEAP. Area values for each catchment are presented in Table 4.

| Catchment ID | CRWR Area ($km^2$) |
|---|---:|
| C13070001 | 11454.10 |
| C13070003 | 2668.04 |
| C13070004 | 5248.60 |
| C13070005 | 2200.31 |
| C13070006 | 3876.92 |
| C13070007 | 11117.80 |
| C13070008 | 7587.57 |
| C13070009 | 2577.56 |
| C13070010 | 1991.00 |
| C13070011 | 2875.22 |
| Total Basin Area | 51597.12 |

Table 4: Catchment Area

### 3.2.3 Crop Coefficient

Crop coefficient (Kc) is a measure of evapotranspiration ability of a crop under optimum conditions. Literally, Kc is the ratio of an observed crop's evapotranspiration (PET) to a reference crop (RET) under the same conditions. Kc includes crop characteristics and averaged effects of evaporation from the soil (FAO). Therefore, it depends on crop type and growing stage/time.

$PET = K_c * RET$

Kc values should be averaged for each catchment in order to enter it in WEAP. WEAP can also process monthly Kc values. Kc values vary between $0<Kc\leq1$ depending on crop type and growing stage. Maximum evapotranspiration, Kc=1, occurs at open water areas, while lower Kc values occur for less evpotranspirative plants and bare land. Kc values for different crops in the Rio Grande/Bravo Basin were determined by using an earlier study's data. The World Bank (2005) conducted a study to analyze sustainable water resources management in the Rio Grande/Bravo Basin. Potential (PET) and actual evapotranspiration (RET) values were determined for the main crops in the basin. Kc values was calculated from these data and are presented in Table 5.

| Land Cover | RET, mm | PET, mm | Kc |
|---|---|---|---|
| Urban Area | 803 | 1048 | 0.77 |
| Water Bodies | 1578 | 1578 | 1.00 |
| Irrigated Agriculture (delta) | 1202 | 1346 | 0.89 |
| Irrigated Agriculture (valley) | 898 | 1040 | 0.86 |
| Supplemental Irrigation | 1242 | 1298 | 0.96 |
| Low Open Forest | 483 | 1272 | 0.38 |
| Oak Forest | 538 | 1747 | 0.31 |
| Pine Forest | 478 | 1272 | 0.38 |
| Chapparal | 481 | 1424 | 0.34 |
| Microphyllous Scrublands | 237 | 501 | 0.47 |
| Scrubland with Rosetted Vegetation | 263 | 616 | 0.43 |
| Thornscrubland Tamaulipan | 583 | 1254 | 0.46 |
| Submontane Scrubland | 711 | 1605 | 0.44 |
| Cultivated Grassland | 516 | 1129 | 0.46 |
| Natural Grassland | 342 | 642 | 0.53 |

Table 5: Crop Coefficient Values

NLCD and UMC land use data were processed in order to determine crop types in percentages for each catchment. Then, their land use classes were matched with the World Bank's land use classes to assign Kc values. After matching land use classes, assigned Kc values for NLCD and UMD land use classes are presented in Table 6.

| **NLCD Land Use Classes** | **Kc** | **UMD Land Use Classes** | **Kc** |
|---|---|---|---|
| Open Water | 1.00 | Water / Goode's Interrupted Space | 1.00 |
| Developed, Open Space | 0.77 | Evergreen Needleleaf Forest | 0.35 |
| Developed, Low Intensity | 0.77 | Evergreen Broadleaf Forest | - |
| Developed, Medium Intensity | 0.77 | Deciduous Needleleaf Forest | - |
| Developed, High Intensity | 0.77 | Deciduous Broadleaf Forest | - |
| Barren Land(Rock/Sand/Clay) | 0.30 | Mixed Cover | 0.45 |
| Deciduous Forest | 0.35 | Woodland | 0.35 |
| Evergreen Forest | 0.35 | Wooded Grassland | 0.38 |
| Shrub/Scrub | 0.45 | Closed Shrubland | 0.45 |
| Grassland/Herbaceous | 0.53 | Open Shrubland | 0.45 |
| Cultivated Crops | 0.46 | Grassland | 0.53 |
| Woody Wetlands | 0.90 | Cropland | 0.88 |
| Emergent Herbaceous Wetlands | 0.90 | Bare Ground | 0.30 |
| | | Urban and Built-Up | 0.77 |

Table 6: Crop Coefficient Values for NLCD and UMD land use classes

Since the NLCD land use map is available in the state scale, the maps for Texas and New Mexico States were opened in ArcMap. First, these two maps were clipped for the Pecos River Basin. Secondly, they were merged to mosaic to a new raster tool in

ArcMap. Then, the tabulate area tool was applied and land use classes were determined in percentages for each catchment, as shown in Table 7. Finally, weighted averages of Kc values for each catchment were calculated.

All UMD land use class data were obtained in one ASCII file. For each land use class, data were separated and converted to grid files. Then, zonal statistics were applied to all 14 land use classes and frequencies of each class were determined for each catchment, as shown in Table 8. As with the NLCD data, weighted averages of Kc values for each catchment were calculated for UMD as well.

Different results were obtained from the NLCD and UMD data sets. While the NLCD results indicate over 90% shrub/scrub for the entire basin, UMD results indicate 39% bare ground, 26% shrub land, and 26% grassland. However, Kc values don't show that much difference. Because the UMD data provides leaf area index values for its land use classes, its Kc values were used in WEAP in order to be coherent. Kc results from the two sources, NLCD and UMC, are compared in Table 9.

| | Open Water | Developed, Open Space | Developed, Low Intensity | Developed, Medium Intensity | Developed, High Intensity | Barren Land (Rock/Sand/ Clay) | Deciduous Forest | Evergreen Forest | Shrub/Scrub | Grassland/ Herbaceous | Cultivated Crops | Woody Wetlands | Emergent Herbaceous Wetlands |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C13070001 | 0.20 | 0.83 | 0.24 | 0.08 | 0.01 | 1.58 | 0.00 | 0.12 | 94.86 | 1.25 | 0.70 | 0.06 | 0.06 |
| C13070003 | 0.08 | 1.07 | 0.15 | 0.01 | 0.00 | 1.30 | 0.13 | 14.87 | 80.20 | 0.58 | 1.22 | 0.18 | 0.20 |
| C13070004 | 0.00 | 0.41 | 0.09 | 0.03 | 0.00 | 1.00 | 0.02 | 2.06 | 91.82 | 4.25 | 0.23 | 0.03 | 0.05 |
| C13070005 | 0.00 | 0.38 | 0.04 | 0.00 | 0.00 | 0.03 | 0.13 | 9.67 | 84.49 | 5.02 | 0.20 | 0.00 | 0.03 |
| C13070006 | 0.00 | 0.78 | 0.12 | 0.01 | 0.01 | 0.04 | 0.01 | 3.85 | 88.56 | 5.53 | 0.86 | 0.05 | 0.19 |
| C13070007 | 0.01 | 0.69 | 0.17 | 0.06 | 0.01 | 2.41 | 0.00 | 0.00 | 79.63 | 16.89 | 0.09 | 0.01 | 0.03 |
| C13070008 | 0.05 | 0.58 | 0.08 | 0.01 | 0.00 | 0.37 | 0.02 | 0.18 | 98.03 | 0.15 | 0.02 | 0.48 | 0.04 |
| C13070009 | 0.00 | 0.71 | 0.12 | 0.00 | 0.00 | 0.51 | 0.00 | 0.12 | 97.63 | 0.48 | 0.34 | 0.04 | 0.05 |
| C13070010 | 0.00 | 0.19 | 0.00 | 0.00 | 0.00 | 0.12 | 0.01 | 0.10 | 99.22 | 0.01 | 0.04 | 0.27 | 0.02 |
| C13070011 | 0.00 | 0.64 | 0.00 | 0.00 | 0.00 | 0.09 | 0.04 | 0.59 | 98.43 | 0.01 | 0.00 | 0.14 | 0.05 |

Table 7: NLCD Land Use Classes in Percentages for Each Catchment

| Catchment ID | Water/ Goode's Interrupted Space | Evergreen Needleleaf Forest | Evergreen Broadleaf Forest | Deciduous Needleleaf Forest | Deciduous Broadleaf Forest | Mixed Cover | Woodland | Wooded Grassland | Closed Shrubland | Open Shrubland | Grassland | Cropland | Bare Ground | Urban and Built-Up |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C13070001 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 | 3.23 | 14.31 | 13.77 | 18.32 | 2.22 | 47.85 | 0.06 |
| C13070003 | 0.12 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 4.88 | 21.83 | 18.09 | 3.11 | 17.43 | 1.46 | 33.04 | 0.00 |
| C13070004 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.22 | 1.76 | 17.49 | 16.64 | 9.35 | 0.08 | 54.47 | 0.00 |
| C13070005 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.41 | 12.64 | 23.59 | 4.56 | 20.11 | 0.07 | 37.63 | 0.00 |
| C13070006 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.10 | 4.57 | 25.97 | 6.02 | 21.02 | 0.59 | 41.64 | 0.06 |
| C13070007 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 7.10 | 12.74 | 10.41 | 29.50 | 0.58 | 39.53 | 0.10 |
| C13070008 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 2.37 | 29.28 | 1.07 | 28.52 | 1.73 | 36.99 | 0.03 |
| C13070009 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.61 | 15.74 | 5.92 | 38.26 | 0.64 | 37.82 | 0.00 |
| C13070010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.33 | 24.37 | 0.93 | 39.62 | 0.00 | 33.76 | 0.00 |
| C13070011 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.38 | 18.57 | 0.20 | 35.71 | 13.45 | 27.69 | 0.00 |

Table 8: UMD Land Use Classes in Percentages for Each Catchment

| Cathment ID | C13070001 | C13070003 | C13070004 | C13070005 | C13070006 | C13070007 | C13070008 | C13070009 | C13070010 | C13070011 |
|---|---|---|---|---|---|---|---|---|---|---|
| UMD Kc | 0.40 | 0.40 | 0.37 | 0.40 | 0.40 | 0.41 | 0.42 | 0.43 | 0.43 | 0.49 |
| NLCD Kc | 0.45 | 0.44 | 0.45 | 0.45 | 0.45 | 0.46 | 0.45 | 0.45 | 0.45 | 0.45 |

Table 9: Kc Results from NLCD and UMD for Each Catchment

### 3.2.4 Leaf Area Index

Literally, leaf area index (LAI) is the ratio of total upper leaf surface of plant cover divided by the land surface area over which it grows. It is used to predict surface runoff response and crop growth. LAI is a dimensionless parameter and it varies with land use. LAI ranges from 0.1 to 10 and higher LAI values cause a decrease in runoff. WEAP can process either monthly or single values.

In order to determine the runoff resistance factor of the land cover, average LAI values were calculated by using UMD land use data. Percentages of land use classes for each catchment were already processed to determine Kc values. The same data were used for LAI as well. Weighted LAI values were calculated by multiplying percentage of a land classes with their monthly LAI values. Then, results were summed up for each catchment. UMD monthly LAI values for each land use class are presented in Table 10 and monthly LAI values for each catchment in the basin are presented in Table 11.

Because most of the basin is covered by bare ground, shrubland, and grassland, LAI values are lower all over the basin. The maximum monthly average LAI value is 1.34 in catchment C13070011, while the minimum LAI value 0.764 in catchment C13070001. The LAI values peak in summer and are minimum in winter.

| UMD Land Use Classes | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water / Goode's Interrupted Space | NONE | NONE | NONE | NONE | NONE | NONE | NONE | NONE | NONE | NONE | NONE | NONE |
| Evergreen Needleleaf Forest | 8.760 | 9.160 | 9.827 | 10.093 | 10.360 | 10.760 | 10.493 | 10.227 | 10.093 | 9.827 | 9.160 | 8.760 |
| Evergreen Broadleaf Forest | 5.117 | 5.117 | 5.117 | 5.117 | 5.117 | 5.117 | 5.117 | 5.117 | 5.117 | 5.117 | 5.117 | 5.117 |
| Deciduous Needleleaf Forest | 8.760 | 9.160 | 9.827 | 10.093 | 10.360 | 10.760 | 10.493 | 10.227 | 10.093 | 9.827 | 9.160 | 8.760 |
| Deciduous Broadleaf Forest | 0.520 | 0.520 | 0.867 | 2.107 | 4.507 | 6.773 | 7.173 | 6.507 | 5.040 | 2.173 | 0.867 | 0.520 |
| Mixed Cover | 4.640 | 4.840 | 5.347 | 6.100 | 7.434 | 8.767 | 8.833 | 8.367 | 7.567 | 6.000 | 5.014 | 4.640 |
| Woodland | 5.276 | 5.529 | 6.006 | 6.443 | 7.245 | 8.364 | 8.540 | 8.127 | 7.253 | 6.329 | 5.626 | 5.301 |
| Wooded Grassland | 2.333 | 2.482 | 2.727 | 3.033 | 3.885 | 5.521 | 6.240 | 5.773 | 4.156 | 3.127 | 2.618 | 2.404 |
| Closed Shrubland | 0.581 | 0.629 | 0.629 | 0.629 | 0.919 | 1.769 | 2.551 | 2.554 | 1.729 | 0.970 | 0.726 | 0.629 |
| Open Shrubland | 0.400 | 0.404 | 0.314 | 0.223 | 0.250 | 0.330 | 0.432 | 0.800 | 1.167 | 0.798 | 0.504 | 0.404 |
| Grassland | 0.782 | 0.893 | 1.004 | 1.116 | 1.782 | 3.671 | 4.782 | 4.227 | 2.004 | 1.227 | 1.004 | 0.893 |
| Cropland | 0.782 | 0.893 | 1.004 | 1.116 | 1.782 | 3.671 | 4.782 | 4.227 | 2.004 | 1.227 | 1.004 | 0.893 |
| Bare Ground | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| Urban and Built-Up | 1.287 | 1.395 | 1.551 | 1.773 | 2.519 | 4.137 | 5.021 | 4.580 | 2.848 | 1.886 | 1.518 | 1.366 |

Table 10: UMD Monthly LAI Values for All Land Use Classes

| Catchment ID | January | February | March | April | May | June | July | August | September | October | November | December | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C13070001 | 0.378 | 0.413 | 0.431 | 0.452 | 0.663 | 1.238 | 1.616 | 1.537 | 0.960 | 0.606 | 0.468 | 0.410 | 0.764 |
| C13070003 | 0.780 | 0.843 | 0.915 | 1.000 | 1.366 | 2.237 | 2.748 | 2.553 | 1.642 | 1.122 | 0.914 | 0.826 | 1.412 |
| C13070004 | 0.295 | 0.318 | 0.319 | 0.320 | 0.455 | 0.826 | 1.098 | 1.098 | 0.775 | 0.488 | 0.364 | 0.316 | 0.556 |
| C13070005 | 0.682 | 0.739 | 0.795 | 0.858 | 1.181 | 1.989 | 2.495 | 2.336 | 1.493 | 0.998 | 0.807 | 0.726 | 1.258 |
| C13070006 | 0.458 | 0.502 | 0.532 | 0.566 | 0.827 | 1.538 | 2.021 | 1.902 | 1.153 | 0.717 | 0.564 | 0.498 | 0.940 |
| C13070007 | 0.520 | 0.571 | 0.613 | 0.659 | 0.961 | 1.764 | 2.261 | 2.099 | 1.246 | 0.803 | 0.637 | 0.565 | 1.058 |
| C13070008 | 0.468 | 0.519 | 0.557 | 0.598 | 0.905 | 1.766 | 2.349 | 2.175 | 1.226 | 0.740 | 0.585 | 0.517 | 1.034 |
| C13070009 | 0.457 | 0.511 | 0.552 | 0.596 | 0.916 | 1.815 | 2.388 | 2.187 | 1.188 | 0.728 | 0.577 | 0.510 | 1.036 |
| C13070010 | 0.486 | 0.544 | 0.591 | 0.638 | 0.984 | 1.962 | 2.603 | 2.382 | 1.282 | 0.772 | 0.615 | 0.543 | 1.117 |
| C13070011 | 0.595 | 0.666 | 0.731 | 0.799 | 1.218 | 2.376 | 3.099 | 2.807 | 1.491 | 0.922 | 0.744 | 0.662 | 1.342 |

Table 11: Monthly LAI Values for Each Catchment

### 3.2.5 Hydraulic Conductivity

Conductivity is a measure of ease of water movement through a porous medium. It varies with intrinsic permeability of the material and the degree of saturation. Conductivity controls the amount of the rainfall flows through to groundwater. Conductivity varies from 1 m/s for coarse materials such as gravel to $10^{-13}$ m/s for very fine materials such as shale (Physical Hydrology, Dingman, 1993). WEAP applies a single or a monthly value in mm/month of conductivity for an entire catchment.

Since the WEAP Soil Moisture Method works with a two bucket system, conductivity values were determined for the deep and root zones. The NLDAS soil data has 11 layers from surface to 250 cm (see Table 12). Each layer has several properties and is presented in separate ASCII files. Soil parameters in each ASCII file is shown in Table 13. The first five layers were assumed to be the root zone and the remaining were assumed to be the deep zone.

| Layer | Thickness Depth, cm | Depth to Bottom, cm |
|---:|---:|---:|
| 1 | 5 | 5 |
| 2 | 5 | 10 |
| 3 | 10 | 20 |
| 4 | 10 | 30 |
| 5 | 10 | 40 |
| 6 | 20 | 60 |
| 7 | 20 | 80 |
| 8 | 20 | 100 |
| 9 | 50 | 150 |
| 10 | 50 | 200 |
| 11 | 50 | 250 |

Table 12: NLDAS Soil Data Layers

| Column | Properties |
|---|---|
| 1 | X Coordinate Index |
| 2 | Y Coordinate Index |
| 3 | Longitude |
| 4 | Latitude |
| 5 | Porosity (%) |
| 6 | Field Capacity (%) |
| 7 | Wilting Point (%) |
| 8 | B Parameter |
| 9 | Saturated Soil Matric Potential (in m of H2O) |
| 10 | Saturated Soil Hydraulic Conductivity (in m/s) |

Table 13: NLDAS Soil Data Representation in ASCII Files

First, conductivity columns were extracted and prepared in ASCII format for each layer in order to convert them to raster files. After converting them to raster format, the first five layers were averaged in to one raster file for the root zone conductivity by using the ArcGIS raster calculator. The same procedure was applied to the remaining 6 raster files to create an averaged raster file for deep conductivity. Finally, the ArcMap zonal statistics tool was applied to calculate both root zone raster file and deep raster file and single conductivity values for each layer in each bucket (see Table 14). Raster files for root zone and deep zone conductivities are shown in Figure 18 and Figure 19. Higher hydraulic conductivities were calculated for catchment No C13070007 which is also mentioned in WAM (RBJCO, 2003).

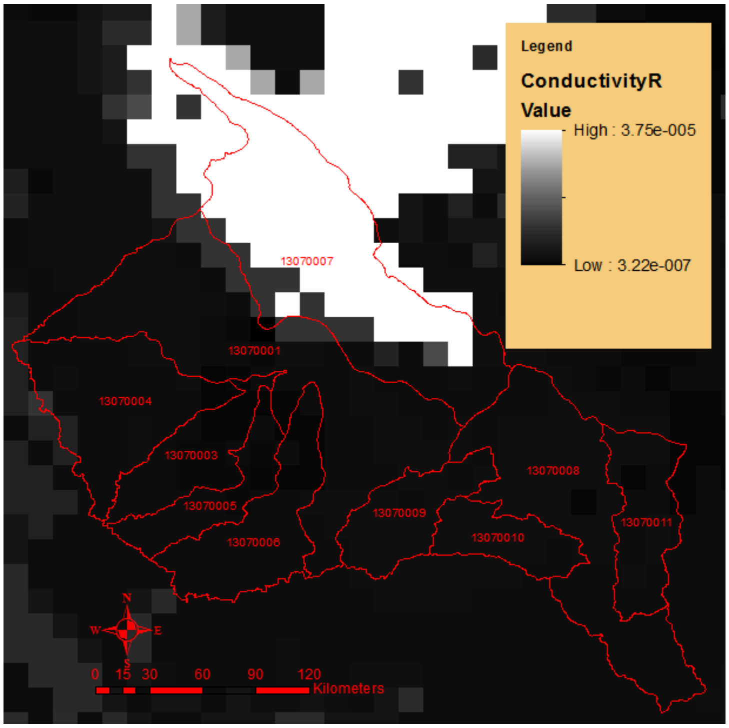


Figure 18: Root Zone Conductivity Raster File

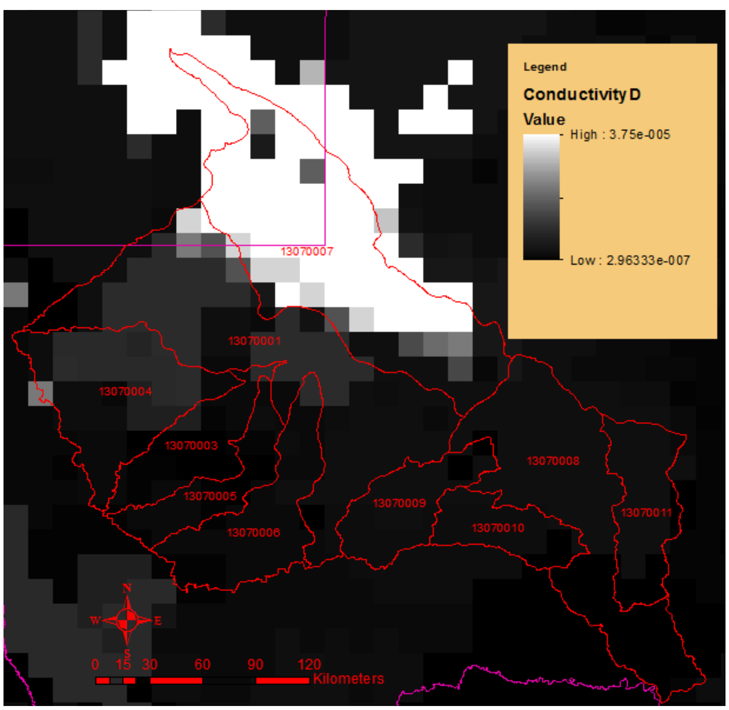


Figure 19: Deep Conductivity Raster File

| Catchment ID | Root Zone Conductivity, mm/month | Deep Conductivity, mm/month |
|---|---|---|
| C13070001 | 4.06 | 7.56 |
| C13070003 | 2.64 | 2.49 |
| C13070004 | 4.17 | 7.01 |
| C13070005 | 2.68 | 1.44 |
| C13070006 | 2.77 | 2.59 |
| C13070007 | 69.80 | 50.69 |
| C13070008 | 3.44 | 2.55 |
| C13070009 | 3.66 | 2.93 |
| C13070010 | 3.64 | 2.52 |
| C13070011 | 3.21 | 2.69 |

Table 14: Conductivities for Deep and Root Zone

### 3.2.6 Water Capacity

Water capacity is a measure of the effective water holding capacity of the soil. WEAP applies a single value of water capacity in mm/month for an entire catchment. NLDAS data was used in order to have an idea about water capacity values. However, the database provides information only for a small depth comparing to deep aquifers in the basin. In general, water capacity for the root zone varies from %2.5 to %25 of the total root zone depth depending on soil type.

The two-bucket rule used to determine conductivity values was applied for water capacities too. However, this time field capacity and wilting point columns were extracted and prepared in ASCII format for each layer in order to create raster files (see Figures 20 and 21). Then, the difference of field capacity from the wilting point was calculated and the results indicate the water capacity in percentages. Water capacity data are represented in percentages of each layer. The calculated water capacity values for the deep and root zones are shown in Table 15.

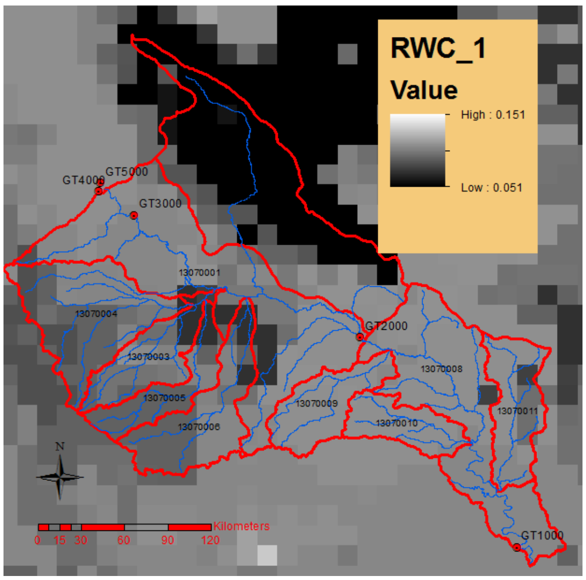


Figure 20: Deep Water Capacity Raster File in Meters

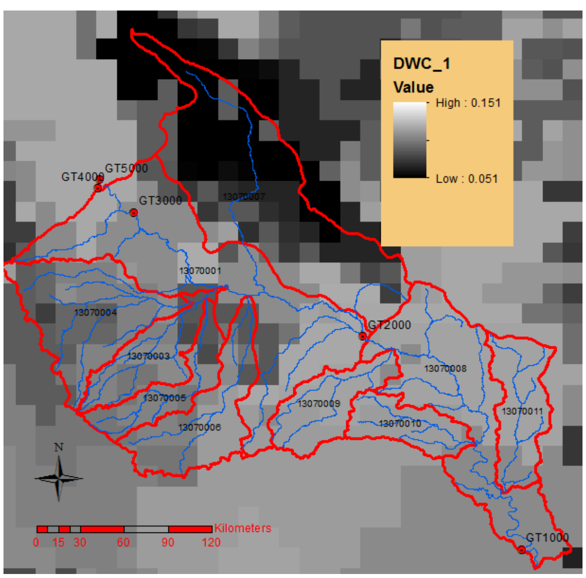


Figure 21: Root Zone Water Capacity Raster File in Meters

| Catchment ID | Root Zone Water Capacity, mm | Deep Water Capacity, mm |
|---|---|---|
| C13070001 | 60 | 200 |
| C13070003 | 56 | 184 |
| C13070004 | 57 | 186 |
| C13070005 | 58 | 182 |
| C13070006 | 57 | 209 |
| C13070007 | 45 | 162 |
| C13070008 | 68 | 215 |
| C13070009 | 69 | 219 |
| C13070010 | 66 | 209 |
| C13070011 | 65 | 224 |

Table 15: Water Capacities for Deep and Root Zone

### 3.2.7 Initial Z

Initial Z is the relative storage in percentage of the total effective water capacity at the beginning of a simulation. The two-bucket rule is also applied to Initial Z, so it is divided into two parts: Initial Z1 for the root zone and Initial Z2 for the deep bucket. WEAP applies a single value in percentage of Initial Z1 and Initial Z2 for an entire catchment. Because these data are not available, Initial Z values were assigned for each catchment.

### 3.2.8 Preferred Flow Direction

Preferred flow direction is used to partition the amount of infiltrated water between interflow and the lower soil layer or groundwater. It affects the distribution of water between the soil layers. Preferred flow direction varies from 0 to 1. 1 indicates 100% horizontal flow direction, while 0 indicates 100% vertical flow. WEAP applies a single or monthly value of preferred flow direction for each catchment. Since it is very difficult to determine flow direction and there is not any available data for it, values of preferred flow direction were assumed.

### 3.2.9 Precipitation

Precipitation includes all forms of atmospheric water including rain, snow, hail, sleet and graupel that falls under gravity. It is the most important parameter of a hydrologic simulation. WEAP accepts monthly total precipitation values in mm for each catchment. Since WEAP can read time series data from a comma separated value (csv) file or it can be entered manually, all climate data were saved in separate csv files.

Precipitation data for this project was obtained in excel files from CRWR. Precipitation, temperature, relative humidity and wind data were prepared for all of the Rio Grande/Bravo Basin from January 1979 to August 2009 from the NARR data. Because NARR data is available in NetCDF format, a python script was written in order to process the data in ArcMap. This python script in conjunction with model builder automated the process of selecting the variable by dimension from the netCDF file, converting it to raster, applying zonal statistics and storing the result in an excel file. This procedure was applied to all months for all climate data. The process takes 45 minutes to complete for each climate variable, for example precipitation. It takes much more time without the script.

Since precipitation can affect a simulation greatly, the data should be processed carefully. In order to be sure that the script is working correctly, the same process was manually applied to NARR precipitation data from 1981 to 2000. First, all data was downloaded month by month. Data for each month was converted to raster. Then, zonal statistics were applied and monthly precipitation results were calculated for each catchment. Because the NARRMON-A data model stores 3-hour averaged monthly data, the results were multiplied by 8 and the number of days in a month. After comparing results from the automated and manual procedures, it was proven that the script was working correctly. Model schema for the manual method and a raster file converted from NetCDF are shown in Figures 22 and 23, respectively. Results for NARR monthly precipitation data are presented in Appendix E.

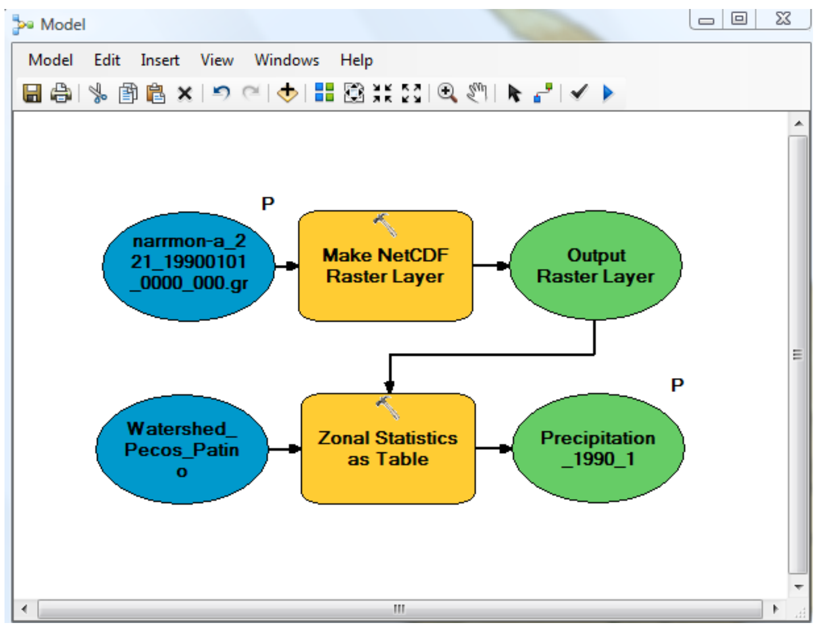


Figure 22: ArcMap Model for Manual Method

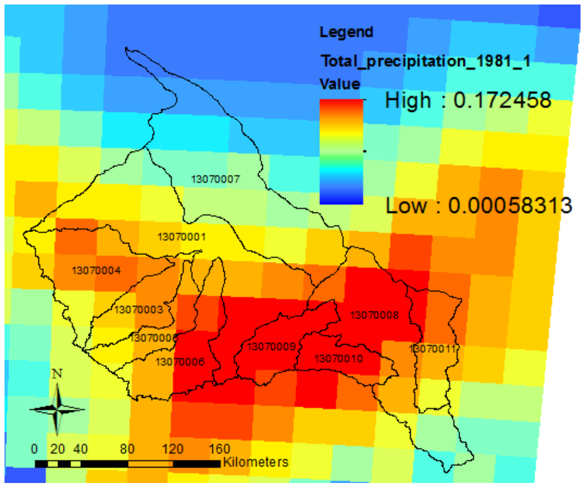


Figure 23: NARR Precipitation Raster

In addition, precipitation data from TWDB were processed to calculate monthly precipitation values for all catchments. Since these data are available in ascii format, they were first converted to raster format, as shown in Figure 24. Then zonal statistics were applied for the entire basin. The results are coherent with the results from NARR, $R^2$= 0.97.

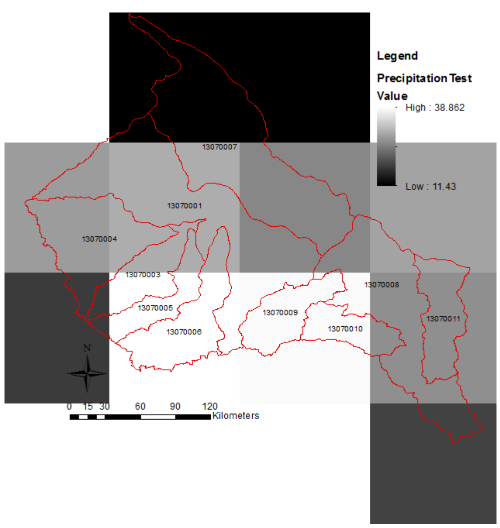


Figure 24: TWBD Precipitation Raster

When the results are examined, it can be seen from the annual average precipitation graph that precipitation decreases with time. While the annual average precipitation is 375 mm for the first ten years, it decreases to 327 mm for the second ten years (see Figure 26). The monthly precipitation trend is almost the same for all catchments (Figure 25). Maximum precipitation, 202 mm/month, occurs on July 1991 and there are some months that have no precipitation. The maximum annual average precipitation, 432 mm, occurs at catchment C13070011, whereas the minimum value, 299 mm, occurs at catchment C13070001 (see Figure 27). Annual average precipitation was calculated to be 351 mm for the entire Pecos River Basin.

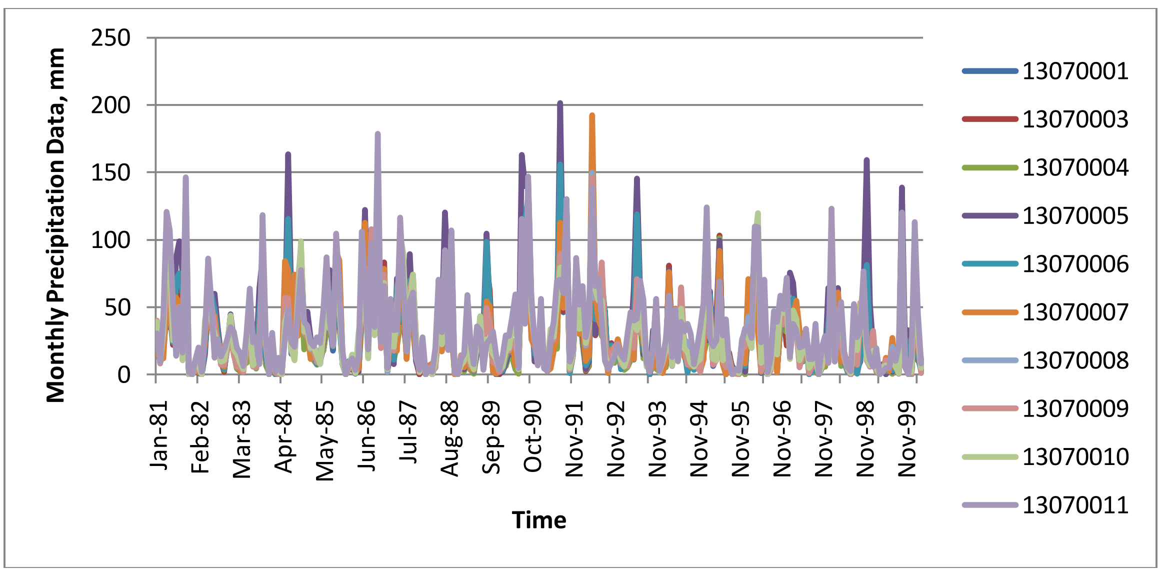


Figure 25: Monthly Precipitation for All Catchments

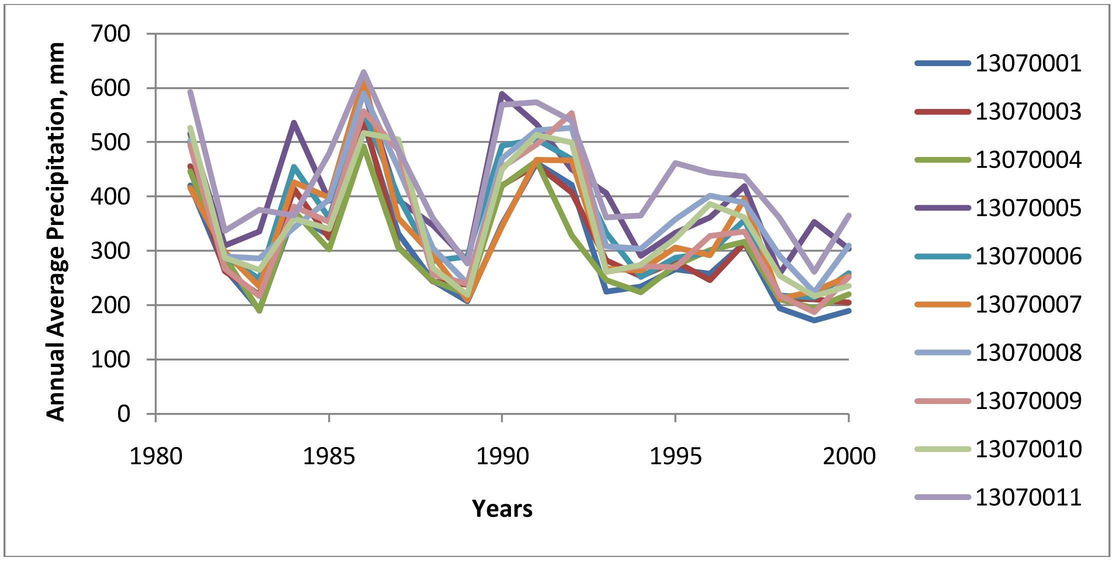


Figure 26: Annual Average Precipitation for All Catchments

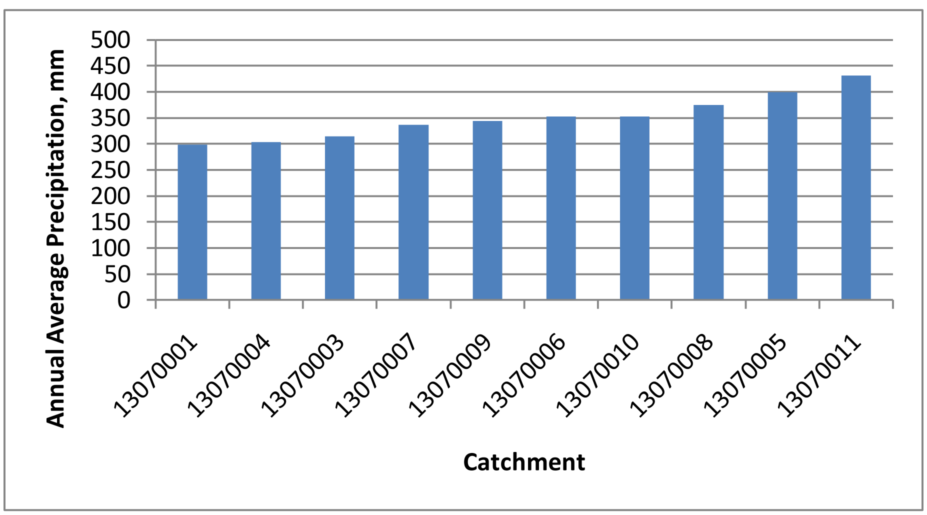


Figure 27: Annual Precipitation Amounts for Each Catchment

Higher precipitation occurs in summer, from May to November, while it is lower in winter. The monthly average precipitation trend varies from catchment to catchment. This variation occurs especially in July (Figure 28). Maximum monthly average precipitation occurs in September, while minimum precipitation occurs in March for the entire Pecos River Basin (see Figure 29).

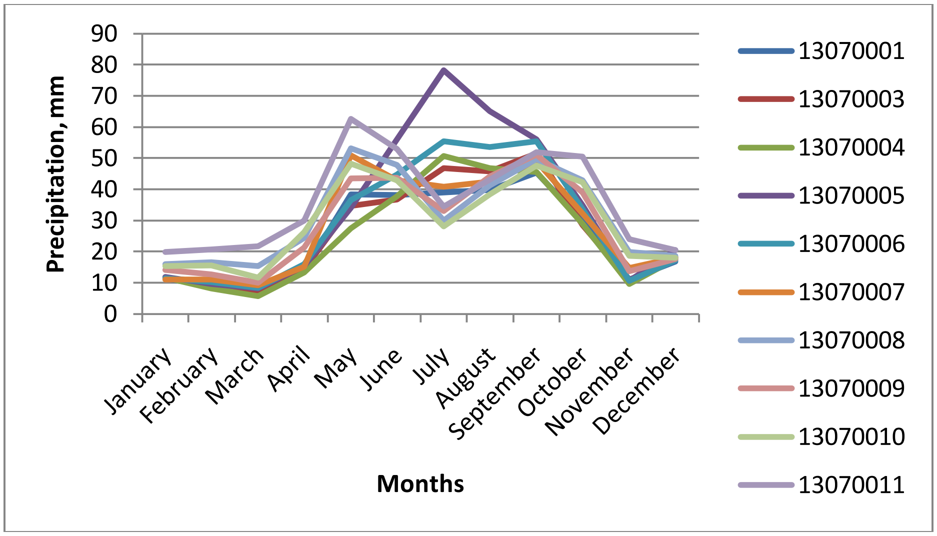


Figure 28: Monthly Average Precipitation for Each Catchment

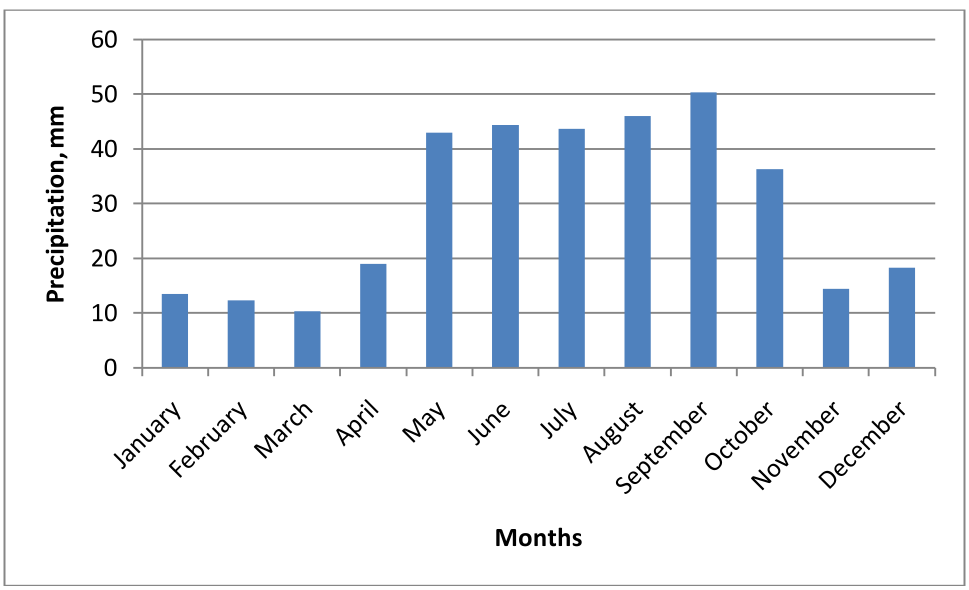


Figure 29: Monthly Average Precipitation for the Entire Basin

### 3.2.10 Temperature

Temperature is another important data for a hydrologic simulation. Temperature and wind control the evapotranspiration process. Temperature and humidity affects precipitation as well. Since the study area has high temperatures, evapotranspiration is very high comparing to other parts of the U.S.

WEAP accepts monthly weighted mean temperature values in $^{o}$C for each catchment. Temperature data, like precipitation, was obtained in excel files. These data were prepared for the entire Rio Grande/Bravo Basin from January 1979 to August 2009 using NARR data. Monthly temperature data for each catchment was saved in a csv file and put into WEAP. Monthly temperature data is presented in Appendix F.

After analyzing the data some important information were acquired. Maximum temperature is around 34 $^{0}$C and it occurs in July, while minimum temperature is around 6.5 $^{0}$C and occurs in January, see Figure 30. There is not much spatial variation over the basin. Temperature and precipitation show an opposite relationship during the 20-year analysis period. When temperature increases, precipitation decreases in the basin. It is possible to analyze the climate change over the basin from Figure 31. Temperature increased 1 $^{0}$C from 1981 to 2000, while annual precipitation decreased an average of 100 mm.

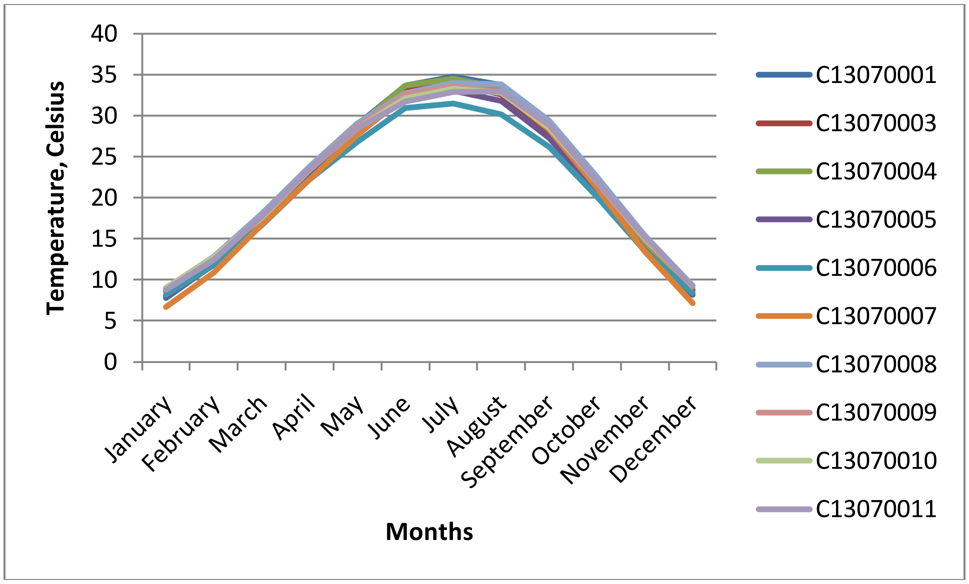


Figure 30: Monthly Temperature Change for Each Catchment

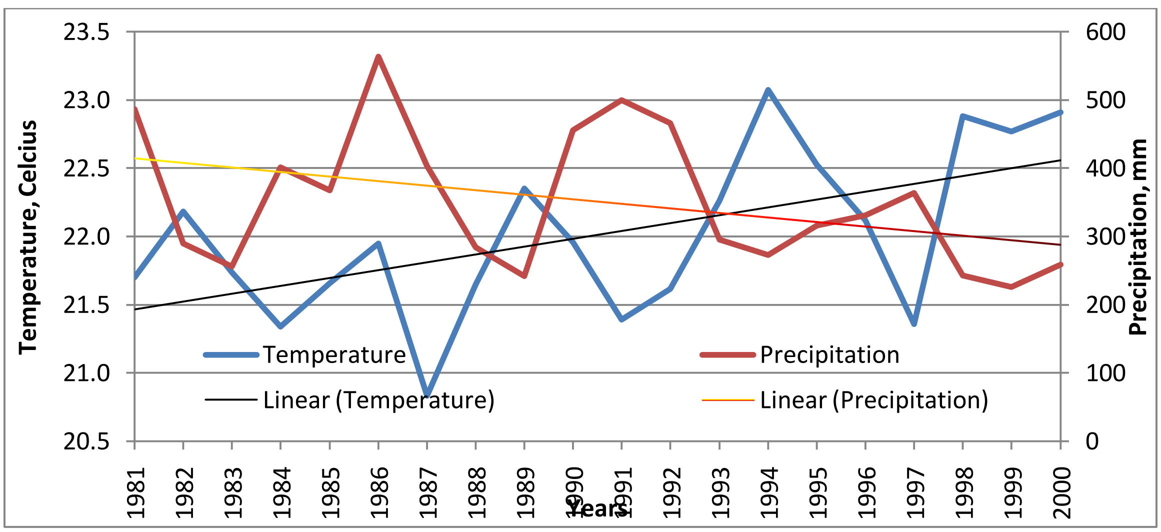


Figure 31: Annual Variations of Temperature and Precipitation in the Basin

### 3.2.11 Relative Humidity

Relative humidity is a measure of water vapor content in the air. It is the source of precipitation. WEAP accepts monthly relative humidity values in percent for each catchment. Relative humidity data, like precipitation and temperature, were obtained in excel files. Monthly data for each catchment were saved in a csv file and put into WEAP. Monthly relative humidity data are presented in Appendix G.

Maximum relative humidity is 73%, while the minimum is 17% and the average is 43% over the basin between 1981 and 2000, see Figure 32. An average of 10% spatial variation occurs. Catchments located below streamflow control point GT2000 have equal or higher relative humidity than the average whereas, the ones located above the control point have lower relative humidity than the average. Temporal variation indicates that relative humidity is lower than the average in spring and summer and it is higher than the average in fall and winter, Figure 33.

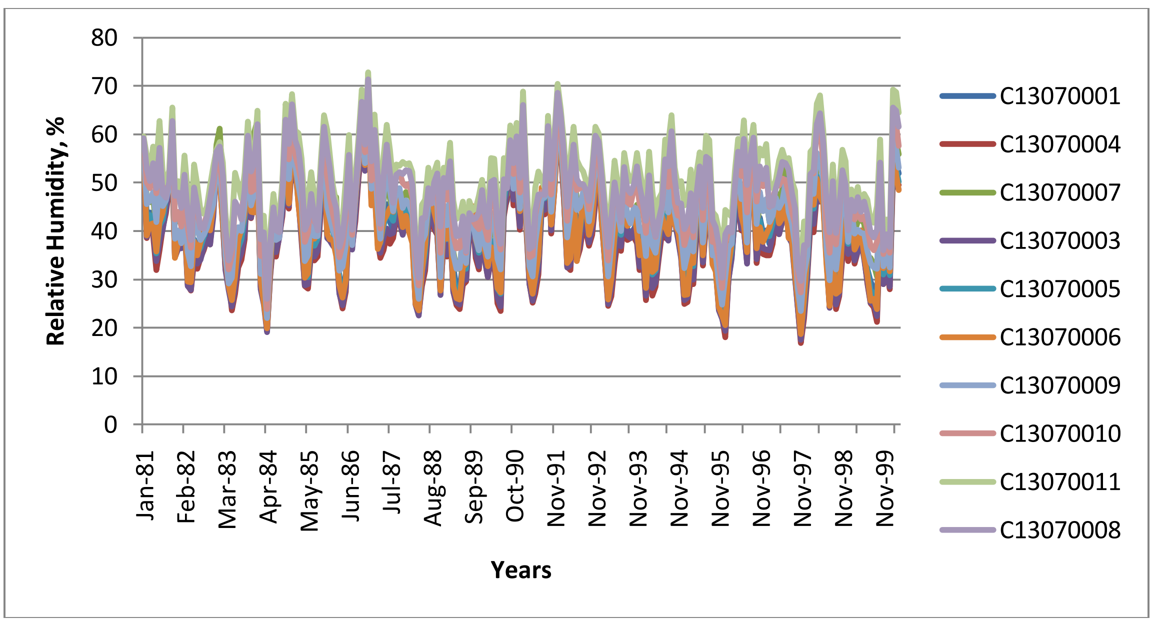


Figure 32: Monthly Relative Humidity, 1981-2000

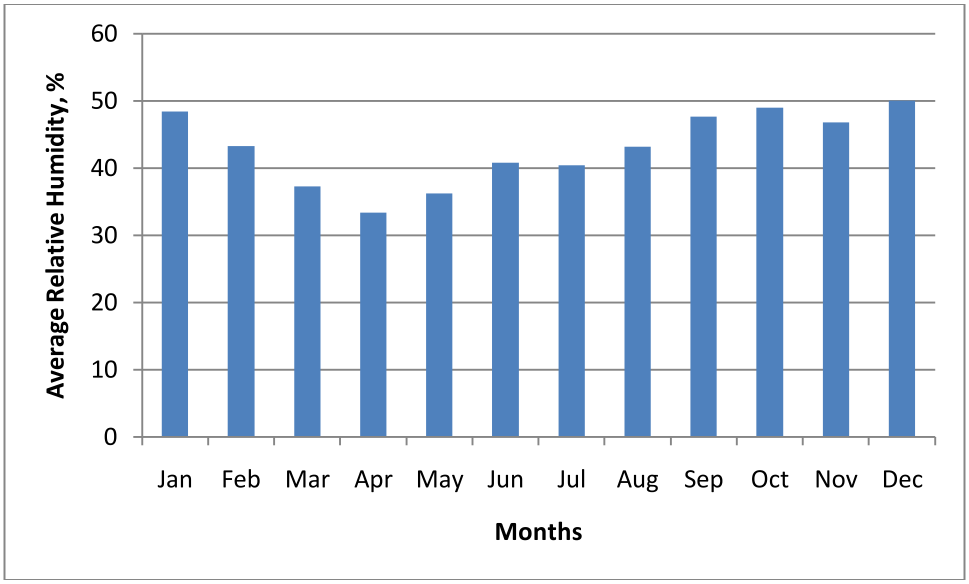


Figure 33: Monthly Average Humidity for the Basin

### 3.2.12 Wind

Average wind speed is another required climate data for the simulation. Wind speed near the surface is important because wind along with temperature controls evapotranspiration. If there is not enough wind to carry away the evaporated water vapor, no more evaporation occurs due to the lack of moisture gradient.

WEAP accepts monthly wind speed values in m/s for each catchment. Wind data as other climate were obtained in excel files. Monthly data for each catchment were saved in a csv file and put into WEAP. Monthly wind speed data are presented in Appendix H.

According to the statistics applied to the data, maximum wind speed is 6.1 m/s, while the minimum is 0.1 m/s and the average is 1.9 over the basin for the study period, Figure 34. Wind data, as with other climate data, indicates that summer is the optimum period of year for precipitation, Figure 35. Temperature is high enough to increase evapotranspiration and there is also enough wind to carry away the evaporated water vapor, and allow more evapotranspiration. There is enough water vapor in the air to evaporate as well, around 40%.

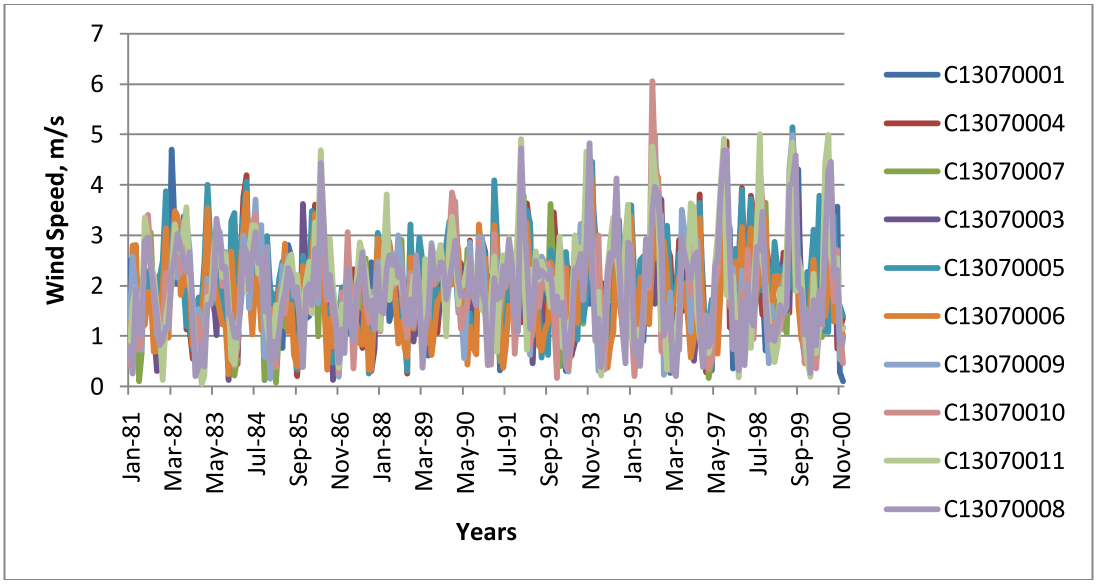


Figure 34: Monthly Wind Speed Data, 1981-200

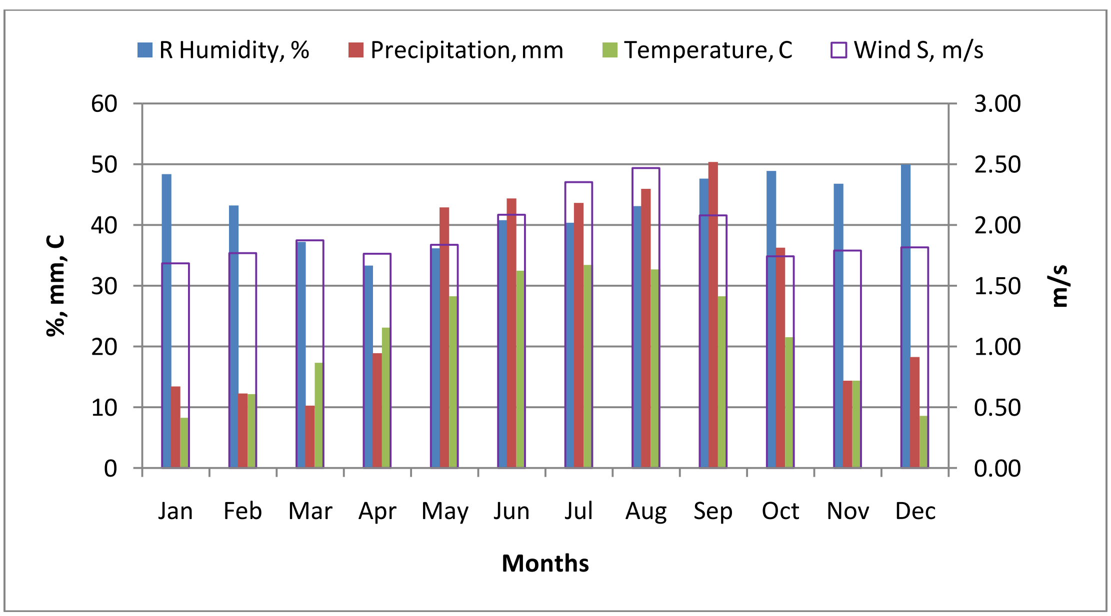


Figure 35: Relationships amongst Climate Data

### 3.2.13 Cloudiness Fraction

Cloudiness fraction is the fraction of the sky obscured by clouds. Cloudiness fraction can help to estimate cooling of the atmosphere. It decreases temperature and incoming solar radiation by reflecting light to space and recycling long wave radiation to the ground. WEAP uses a single or monthly value of cloudiness fraction for each catchment. Value ranges from 0 to 1. 0 indicates completely overcast, while 1 indicates no clouds. Default values, 1 (no cloud), were set up for this parameter.

### 3.2.14 Latitude

Latitude in degrees for each catchment is also required by WEAP. It is used to calculate losses in Soil Moisture Method and water temperature in water quality modeling. Latitude data was estimated from Figure 36 and they are shown in the Table 16.

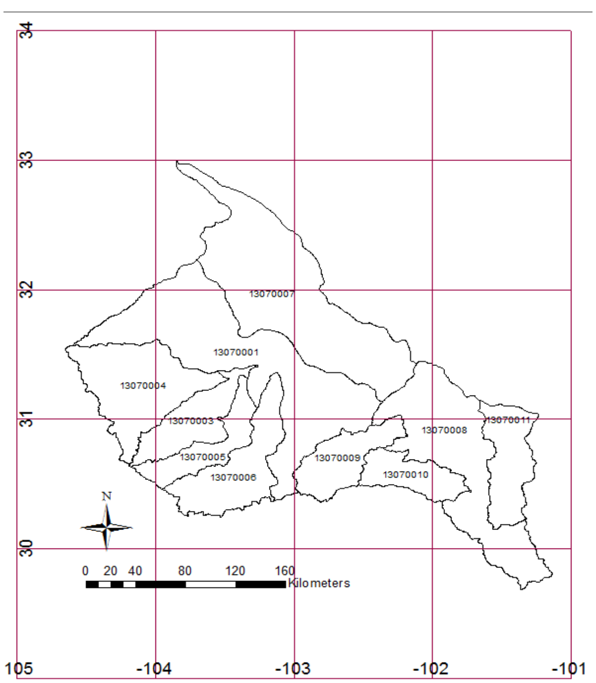


Figure 36: Latitudes and Longitudes of the Basin

| Catchment ID | Latitude |
|---|---|
| C13070001 | 31.50 |
| C13070003 | 31.00 |
| C13070004 | 31.25 |
| C13070005 | 31.00 |
| C13070006 | 31.00 |
| C13070007 | 32.00 |
| C13070008 | 30.50 |
| C13070009 | 30.75 |
| C13070010 | 30.50 |
| C13070011 | 30.50 |

Table 16: Latitude for Each Catchment

### 3.2.15 Initial Snow

Initial Snow data is only needed for the first year of the simulation. It represents the initial snow value of January 1981. Since precipitation of snow can become streamflow in the study period, the Soil Moisture Method considers it as an input as well. Because snow didn’t occur in January 1981 (wunderground.com), a value of 0 was used for each catchment.

### 3.2.16 Melting Point

Melting Point is the threshold for snow melt. It is important for calculating snow melt contribution to the streamflow. However, these data don’t have a great impact for this study, since the climate of the study area is not cold enough for snow accumulation. A monthly value of 0 was assigned for each catchment.

### 3.2.17 Freezing Point

Freezing Point is the threshold for snow accumulation. As with Melting Point, these data are not significant for this study because of the climatic conditions. A monthly value of 0 was assigned for each catchment.

### 3.2.18 Snow Accumulation Gauge

Snow Accumulation Gauge represents the amount of water contained within the snowpack. Monthly melt water equivalent depth is needed for calculating the snow melt contribution to the streamflow. WEAP processes these data for monthly variations in mm unit. These data are important for snowfed basins; however snow accumulation is not significant and can be ignored in the Pecos River Basin. A monthly value of 0 was assigned for each catchment.

### 3.2.19 Naturalized Streamflows

Monthly naturalized streamflow data from January 1981 to December 2000 were used to calibrate and validate the simulation. Naturalized streamflow data from TCEQ gages Delaware R nr Red Bluff, NM (GT5000) and Pecos R at Red Bluff, NM (GT4000) were entered in the simulation as head flows. Data from two other gages, gage No GT2000 and GT1000, were also entered in WEAP as streamflow gauge data in order to be used for calibration and simulation. These data are in cubic meters per second units and saved in cvs files. Naturalized streamflow for gauges GT5000+GT4000 is presented in Appendix I.

Streamflow data were analyzed in order to understand the response of the basin in two locations, GT2000 and GT1000 (see Figure 37). GT2000 represents the response of the upper basin, while GT1000 represents the response of the whole basin. For the entire basin, maximum streamflow is 40.04 $m^3/s$ and occurred in October 1981, while the minimum streamflow is 1.28 $m^3/s$ and occurred in July 1998 and the average is 6.92 $m^3/s$. For the upper basin, maximum streamflow is 29.34 m3/s occurred in June 1986 and the average is 2.05 m3/s. There are some dates that the streamflow is 0 for the upper basin because of the negative results in the WAM Project. Even though the upper basin occupies 2/3 of the total basin area, there is a huge difference between the streamflows of the upper and entire basin. Geological formations in the basin can cause this difference, since climatic conditions don't change significantly spatially. Streamflow makes unexpected peaks especially in the first years of the simulation.

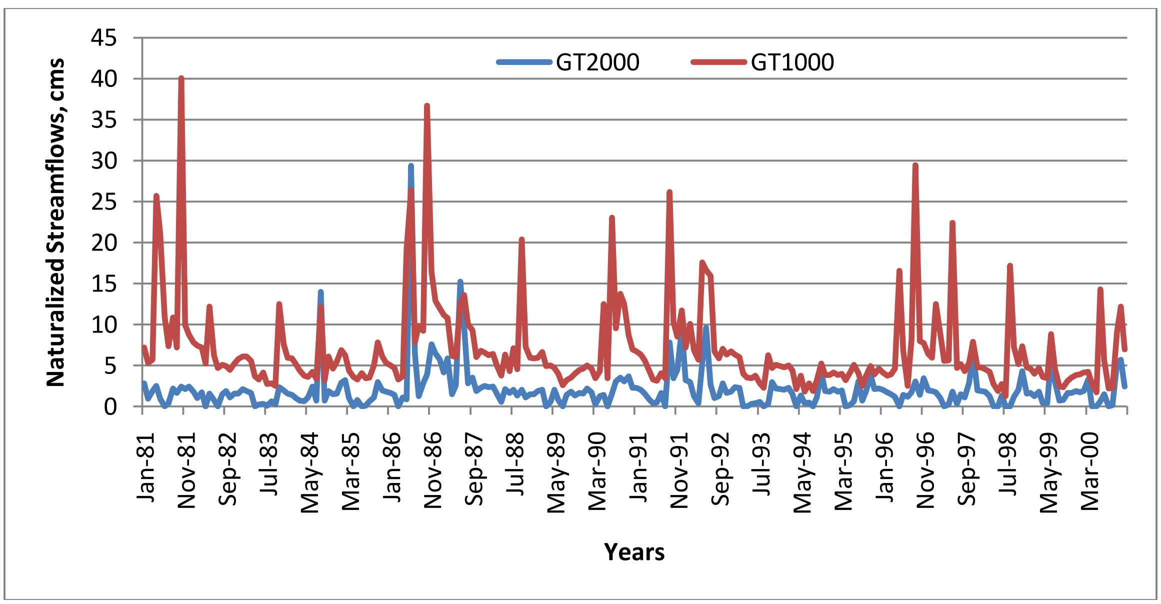


Figure 37: 20-Year Monthly Naturalized Streamflows in $m^3/s$.

Monthly average streamflow has a peak in October, while it is minimum in April for the entire basin (see Figure 38). There is an unexpected decrease in July and August, while precipitation is still high. High temperatures may cause this situation. Monthly values don't match between the upper and whole basin in the fall. There is a 100 times difference in magnitude between rainfall and runoff.

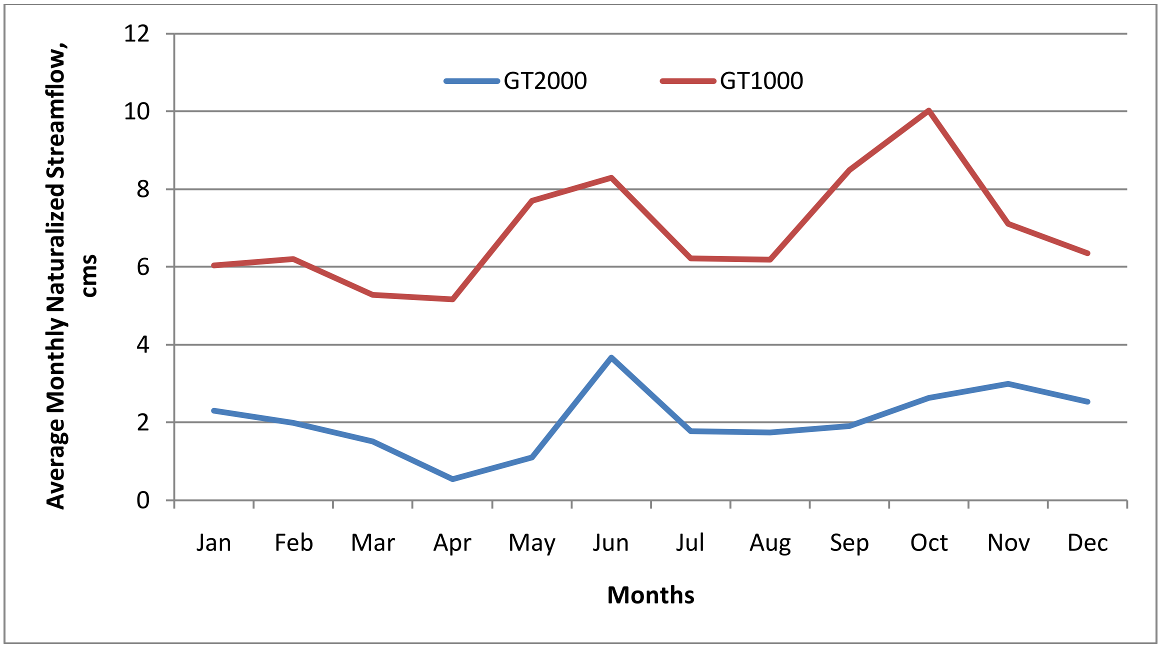


Figure 38: Average Monthly Naturalized Streamflows

### 3. 3 Model Calibration

In this section, the model calibration process is explained. Definitions, hydrologic effects and calculated values of each calibration parameter are presented under the data preprocessing section. Responses of streamflow to each parameter are analyzed and the final values after the calibration process are presented in this section. First, a comprehensive calibration process was applied and the best results were kept as reference. Then, another calibration process was applied in order to control reference results and show the effects of each parameter relative to reference. In some cases, direct results of the second calibration are presented instead of comparing to reference. The idea of exhibiting the effects of each parameter is to provide a basic understanding of how each parameter affects the model and in what magnitude.

Calibration was applied for the first 10 year period, 1981 – 1990. Calibration parameters are: Soil Water Capacity, Root Zone Conductivity, Initial Z1, Deep Water Capacity, Deep Conductivity, Initial Z2, Preferred Flow Direction, Crop Coefficient and Runoff Resistance Factor. The Parameter Estimation Tool (PEST) was also used for calibration; however better results were obtained with manual calibration. Calibration parameters usually vary between the upper and downstream basins (basins above and below the GT2000 TCEQ gauge) due to their different geologic structures.

### 3.3.1 Soil Water Capacity

Soil water capacity (SWC) has an impact on streamflow depending on its magnitude. After a long calibration process an average soil water capacity value of 1500 mm was assigned for the upper basin sub-catchments: C13070001, C13070003, C13070004, C13070005, C13070006, and C13070007. Also, an average value of 1000 mm was assigned for the downstream sub-catchments: C13070008, C13070009, C13070010, and C13070011. In order to analyze the response of soil water capacity in different magnitudes, this assignment was used as the reference.

First, lower values than the reference were applied such as 0.1 and 0.5 times and each resulted with higher streamflows as expected. Then, higher values than the reference were applied. Extreme high values resulted in an increase in streamflow, while smaller increments decreased the streamflow.  The difference between simulated and observed naturalized flows in volume for the entire basin versus different soil water capacities are presented in Table 17. Since the reference values statistically provided the best results, they were kept (see Table 18).

| Relative change in SWC, Times Reference | Errors in Volume | Relative Change |
|---|---|---|
| 10X decrease | 40% | increase |
| 2X decrease | 10% | increase |
| 2X increase | -0.30% | decrease |
| 3X increase | -1.40% | decrease |
| 10X increase | 0.60% | increase |
| 13X increase | 1.80% | increase |

Table 17: Response of SWC in Different Magnitudes

| Catchment ID | Deep Water Capacity, mm | Deep Conductivity, mm/month | Initial Z2, % | Root Water Capacity, mm | Initial Z1, % | Preferred Flow Direction | RRF |
|---|---|---|---|---|---|---|---|
| C13070001 | 250000 | 1 | 3 | 1500 | 5 | 0 | 5 |
| C13070003 | 220000 | 0.8 | 2 | 1300 | 4 | 0 | 4.2 |
| C13070004 | 245000 | 1.3 | 4 | 1700 | 6 | 0 | 4.2 |
| C13070005 | 200000 | 0.8 | 2.5 | 1450 | 4.5 | 0 | 4.2 |
| C13070006 | 240000 | 1.1 | 3.5 | 1550 | 5.5 | 0 | 4.2 |
| C13070007 | 250000 | 1 | 3 | 1500 | 5 | 0 | 5 |
| C13070008 | 250000 | 5 | 7 | 1000 | 22 | 0.2 | 4 |
| C13070009 | 220000 | 4 | 6 | 900 | 20 | 0.18 | 3 |
| C13070010 | 180000 | 6 | 8 | 1100 | 24 | 0.22 | 3 |
| C13070011 | 200000 | 5 | 7 | 1000 | 22 | 0.2 | 3 |

Table 18: Final Calibration Parameters after Calibration Process

### 3.3.2 Root Zone Conductivity

Root zone conductivity (RZC) has effects on surface runoff, interflow, and percolation to the deep zone. It can vary monthly depending on water content in the soil. Using monthly values of RZC helps to adjust average monthly streamflow results. Higher RZC values were assigned for the months with high precipitation, and lower values were assigned to the low precipitation months. Also, higher RZC values in average were assigned for the upper basin sub-catchments. In general, lower RZC values provide higher streamflows, while the higher values provide lower streamflows. However, some catchments have some points of change where streamflow production trend changes. For example, an increase in RZC produces higher streamflows after a certain range of value in catchments: C1307001, C1307004, and C1307007. Statistically best results are kept, as shown in Table 19.

| Catchment ID | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13070001 | 40 | 60 | 60 | 100 | 100 | 70 | 120 | 140 | 150 | 130 | 60 | 80 |
| 13070003 | 5 | 50 | 50 | 1300 | 480 | 340 | 1080 | 1400 | 1000 | 340 | 20 | 375 |
| 13070004 | 10 | 90 | 90 | 340 | 300 | 240 | 260 | 420 | 400 | 235 | 40 | 280 |
| 13070005 | 5 | 50 | 150 | 1780 | 440 | 220 | 1520 | 1600 | 980 | 200 | 20 | 195 |
| 13070006 | 5 | 70 | 70 | 1260 | 350 | 155 | 1150 | 1400 | 1150 | 200 | 10 | 250 |
| 13070007 | 40 | 90 | 90 | 130 | 130 | 100 | 150 | 170 | 180 | 160 | 90 | 110 |
| 13070008 | 125 | 125 | 125 | 125 | 150 | 125 | 125 | 125 | 175 | 220 | 175 | 125 |
| 13070009 | 125 | 125 | 125 | 125 | 145 | 125 | 125 | 125 | 175 | 210 | 175 | 125 |
| 13070010 | 125 | 125 | 125 | 125 | 135 | 125 | 125 | 125 | 175 | 225 | 175 | 125 |
| 13070011 | 125 | 125 | 125 | 125 | 150 | 125 | 125 | 125 | 175 | 220 | 175 | 125 |

Table 19: Monthly Values of RZC in mm/month after Calibration Process

### 3.3.3 Initial Root Zone Water Capacity, Initial Z1

Initial root zone water capacity (Z1) has an impact on streamflow depending on its magnitude, similar to SWC. After a long calibration process an average Z1 of 5% was assigned for the upper basin sub-catchments: C13070001, C13070003, C13070004, C13070005, C13070006, and C13070007. In addition, an average Z1 of 22% was assigned to the downstream sub-catchments: C13070008, C13070009, C13070010, and C13070011. In order to analyze the response different magnitudes of Z1, this assignment was used as a reference.

Since Initial Z1 is the relative value of total effective storage in the root zone at the beginning of the simulation, it only affects the first years of the simulation. In general, lower Z1 values decrease the streamflow, whereas higher Z1 values increase the streamflow. In addition, changes of the values in the downstream sub-catchments cause more changes in the results. Relative changes in results for different Z1 values are presented in Table 20. Since reference values provided statistically the best results, they were kept, see Table 18.

| Catchment ID | Relative Change in Z1, Times Ref | Errors in Volume for Upper Basin | Errors in Volume for Entire Basin | Relative Change |
|---|---|---|---|---|
| C13070001 | 5X increase | 0.5% increase | <0.1% increase | increase |
| C13070001 | 5X decrease | 0.2% decrease | <0.1% decrease | decrease |
| C13070003 | 7.5X increase | 0.2% increase | <0.1% increase | increase |
| C13070003 | 4X decrease | <0.1% decrease | <0.1% increase | decrease |
| C13070008<br>C13070009 | 1.5X increase | No influence | 2% increase | increase |
| C13070010<br>C13070011 | 4X increase | No influence | 5% decrease | decrease |

Table 20: Response of Initial Z1 in Different Magnitudes

### 3.3.4 Deep Water Capacity

Since the basin is located on several different aquifers, high values of deep water capacities (DWC) were assigned. After many trials an average DWC of 230000 mm was assigned for the upper basin sub-catchments: C13070001, C13070003, C13070004, C13070005, C13070006, and C13070007. Also, an average DWC of 212500 mm was assigned for the downstream sub-catchments: C13070008, C13070009, C13070010, and C13070011. In order to analyze the response of streamflow to different magnitudes of DWC, this assignment was used as reference.

Lower values of DWC than the reference were applied, such as 100 and 10 times. While the 100 times less than reference values of DWC have a significant impact on streamflow, 10 times less didn't produce a recognizable change. Higher DWC values than the reference resulted in small increments of streamflow. Differences between simulated and naturalized flow volumes for different magnitudes of DWC are presented in Table 21. Since reference values provided the best results, they were kept, see Table 18.

| Catchment ID | Relative Change in DWC, times reference | Errors in Volume for upper basin | Errors in Volume for Entire Basin | Relative change |
|---|---|---|---|---|
| C13070003 | 100X decrease | 10% increase | 1.6% increase | increase |
| C13070003 | 10X decrease | 0.1% increase | <0.1% increase | increase |
| C13070005 | 100X decrease | 18% increase | 3.1% increase | increase |
| C13070005 | 10X decrease | 0.3% increase | 0.1% increase | increase |
| C13070008-9 | 100X decrease | No influence | 10% increase | increase |
| C13070010-11 | 10X decrease | No influence | 1% decrease | increase |

Table 21: Response of DWC in Different Magnitudes

### 3.3.5 Deep Conductivity

After several trials, a single value for deep conductivity was assigned for each catchment. This assignment was accepted as reference and different monthly values of deep conductivity (DC) were applied in to analyze the response compared to the reference. Even though, good results are obtained with monthly DC, they are still not as good as the reference. Thus, the reference values were kept, Table18.

In general, higher values of DC corresponded to high streamflow values, while the lower values resulted in lower values. Jointly, the behavior of DC and DWC were also analyzed; however the effect of DWC was not significant. Table 22 shows the effects of DC compared to the reference in Catchment C13070001 as an example.

| Catchment ID | Relative Change in DC, Times Ref | Errors in Volume for Upper Basin | Errors in Volume for Entire Basin | Relative Change |
|---|---|---|---|---|
| C13070001 | 10X increase | 35% increase | 6.1% increase | increase |
| C13070001 | 10X decrease | 4% decrease | 0.7% decrease | decrease |

Table 22: Response of DC in Different Magnitudes

### 3.3.6 Initial Deep Water Capacity, Initial Z2

Initial deep water capacity (Z2) affects only the first couple of years of simulation depending on its magnitude and it affect on base flow. After a long calibration process an average Z2 of 3% was assigned for the upper basin sub-catchments: C13070001, C13070003, C13070004, C13070005, C13070006, and C13070007. In addition, an average Z2 of 5% was assigned for the downstream sub-catchments: C13070008, C13070009, C13070010, and C13070011. These values were accepted as reference and different Z2 values were applied to analyze the response of Z2.

First, different Z2 values were applied to the upper basin sub-catchments to analyze their contribution to the streamflow. Then, same process was applied to downstream sub-basins. In general, lower Z2 values decreases the streamflow, while higher Z2 values increases the streamflow. Relative changes in results against different Z2 values are presented in Table 23. The most appropriate values for Z2 were kept, Table 18.

| Catchment ID | Change in Z1 | Errors in Volume for Upper Basin | Errors in Volume for Entire Basin | Relative change |
|---|---|---|---|---|
| C13070001<br>C13070003<br>C13070004<br>C13070005<br>C13070006<br>C13070007 | 3→5 increase | 2.2% increase | 0.4% increase | increase |
| | 3→2 decrease | 1.4% decrease | 0.3% decrease | decrease |
| C13070008<br>C13070009<br>C13070010<br>C13070011 | 5→7 increase | No influence | 0.7% increase | increase |
| | 5→3 decrease | No influence | 0.5% decrease | decrease |

Table 23: Response of Initial Z2 in Different Magnitudes

### 3.3.7 Crop Coefficient

Crop coefficient (Kc) is a measure of evapotranspiration ability of a crop and it has a linear relationship with evapotranspiration. Since Kc varies with land use and season, both single and monthly values were tried.

First, single values for each catchment were used to analyze its response. Higher values of Kc resulted in lower streamflow due to high evapotranspiration losses, while lower values resulted in drastically higher streamflow discharges. It can be inferred from the results that the model is very sensitive to the changes in Kc. The responses of streamflow to different Kc values are shown in Table 24. Monthly values of Kc provided better results for entire basin; however high error in volume occurred for the upper basin. Thus, the reference values were kept, Table 25.

| Kc | Errors in Volume for Upper Basin | Errors in Volume for Entire Basin |
|---|---|---|
| 0.2 | 120.6% | 163.4% |
| 0.5 | 12.4% | 7.8% |
| 0.8 | 0.8% | -38.5% |

Table 24: Response of Kc in Different Magnitudes

| Catchment ID | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13070001 | 0.45 | 0.35 | 0.2 | 0.25 | 0.5 | 0.5 | 0.45 | 0.54 | 0.8 | 0.8 | 0.4 | 0.8 |
| 13070003 | 0.45 | 0.35 | 0.25 | 0.35 | 0.5 | 0.5 | 0.45 | 0.65 | 0.8 | 0.8 | 0.35 | 0.8 |
| 13070004 | 0.45 | 0.3 | 0.2 | 0.25 | 0.4 | 0.5 | 0.55 | 0.65 | 0.8 | 0.8 | 0.35 | 0.8 |
| 13070005 | 0.45 | 0.3 | 0.2 | 0.25 | 0.4 | 0.65 | 0.65 | 0.7 | 0.8 | 0.8 | 0.25 | 0.8 |
| 13070006 | 0.45 | 0.6 | 0.2 | 0.3 | 0.45 | 0.65 | 0.6 | 0.7 | 0.8 | 0.8 | 0.35 | 0.75 |
| 13070007 | 0.45 | 0.55 | 0.25 | 0.35 | 0.75 | 0.65 | 0.5 | 0.6 | 0.8 | 0.8 | 0.7 | 0.8 |
| 13070008 | 0.6 | 0.65 | 0.3 | 0.4 | 0.6 | 0.5 | 0.3 | 0.35 | 0.8 | 0.8 | 0.55 | 0.8 |
| 13070009 | 0.6 | 0.45 | 0.2 | 0.4 | 0.6 | 0.5 | 0.3 | 0.52 | 0.8 | 0.8 | 0.4 | 0.8 |
| 13070010 | 0.6 | 0.6 | 0.2 | 0.5 | 0.65 | 0.45 | 0.3 | 0.4 | 0.8 | 0.9 | 0.5 | 0.8 |
| 13070011 | 0.75 | 0.7 | 0.38 | 0.45 | 0.75 | 0.55 | 0.3 | 0.35 | 0.8 | 0.9 | 0.6 | 0.8 |

Table 25: Monthly Values of Kc after Calibration Process

### 3.3. 8 Preferred Flow Direction

Preferred flow direction (PFD) controls the water partitioning between interflow and percolation. Since there is no available information about this parameter, the values of PFD were assumed. After many trials, the best values were determined and shown in Table 18. Four random trials were applied in order to demonstrate the effects of in PFD different magnitudes, Table 26. First, a value of 0 was applied and low streamflow discharges were calculated. Then, values of 0.2, 0.5 and 0.8 were applied consecutively. Higher values of PDF resulted in higher streamflows with a drastic increase in each trial. It can be inferred from the results that the model is highly sensitive to the changes in PDF and there is no way to calculate it. Many factors can affect PDF and the change might not occur with an order. This is an important weakness of soil moisture method.

| PDF | Errors in Volume for Upper Basin | Errors in Volume for Entire Basin |
|---|---|---|
| 0 | 9.80% | -65.20% |
| 0.2 | 480.6% | 82.1% |
| 0.5 | 1188% | 303.4% |
| 0.8 | 1897% | 525% |

Table 26: Response of PDF in Different Magnitudes

### 3.3.9 Runoff Resistance Factor

Runoff resistant factor (RRF) has a significant effect on surface runoff. Since it depends on land use, it varies seasonally. Thus, both single and monthly values of RRF were applied. At the end, average single values of RRF of 4.5 for the upper basin sub-catchments and 3.3 for downstream sub-catchments were determined as the best values for the model, Table 18.

In addition, RRF values of different magnitudes were applied to demonstrate its effects on streamflow. First, a value of 2 was applied and extremely high streamflow discharges were calculated. Then, values of 5 and 8 were applied consecutively. Higher values of RRF resulted in lower streamflows, see Table 27. Therefore, it can be inferred that the model is highly sensitive to the changes in RRF.

| PDF | Errors in Volume for Upper Basin | Errors in Volume for Entire Basin |
|---|---|---|
| 2 | 385.50% | 127.10% |
| 5 | 6.4% | -12.4% |
| 8 | 1.1% | -14.9% |

Table 27: Response of RRF in Different Magnitude

## 3.4 STATISTICAL COMPUTATIONS

Since calibration and validation processes were applied for a long period of time, two sequential 10-year periods, statistics-based measures were used to evaluate goodness-of-fit and analyze the performance of the model. Comparisons were made between monthly simulated streamflow results and naturalized flows (WAM by RJBCO, 2003).

Fundamental statistics-based measures were analyzed such as mean flows, median, standard deviation (STDEV), mean absolute error (MAE), root mean square error (RMSE), Pearson's correlation, coefficient of determination and error in volume. Alternative statistical measurements such as Index of Agreement (IA) and Nash–Sutcliffe model efficiency coefficient (E) were also used in order to overcome many of the limitations of correlation and correlation-based measures (Legates and McCabe, 1999). The mathematical expressions of all statistical computations used in this project are presented below.

1. Mean:

$$\bar{Q} = \frac{1}{N}\sum_{i=1}^{N} Qo_i$$

2. Standard Deviation (STDEV):

$$STDEV = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Qo_i - \bar{Q})^2}$$

3. Mean Absolute Error (MAE)

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|Qo_i - Qs_i\right|$$

4. Root Mean Square Error (RMSE):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Qo_i - Qs_i)^2}{N}}$$

5. Error in Volume:

$$VE = \frac{(V_o - V_s)}{V_o}x100$$

6. Nash–Sutcliffe model efficiency coefficient:

$$E = 1.0 - \frac{\sum_{i=1}^{N}(Qo_i - Qs_i)^2}{\sum_{i=1}^{N}(Qo_i - \bar{Q})^2}$$

Nash–Sutcliffe model efficiency coefficient compares the simulated results with observed mean. It ranges from -∞ to 1. When E gets closer to 1, it corresponds to a perfect match of modeled results to observed data. When E equals to 0, it indicates the simulated results are as accurate as the mean of the observed data. Values of E below 0 indicate that the observed mean is a better predictor than the model (Legates and McCabe, 1999). Modified Nash coefficient is calculated the same as the Nash coefficient without taking squares of numerator and denominator. Values of the Nash coefficient for mean and median were analyzed and are presented in the results section.

7. Index of Agreement:

$$IA = 1.0 - \frac{\sum_{i=1}^{N} (Qo_i - Qs_i)^2}{\sum_{i=1}^{N} \left( \left| Qs_i - \bar{Q} \right| - \left| Qo_i - \bar{Q} \right| \right)^2}$$

Index of agreement is a measure of the ratio between the mean square error and the potential error, denominator in the equation, multiplied by N and then subtracted from unity (Willmott, 1984). It varies from 0 to 1 and the closer the index of agreement is to 1, the more accurate the model. The modified index of agreement is calculated the same as IA without taking squares of numerator and denominator. Values of IA for the mean and median were analyzed and are presented in the results section.

# Chapter 4: Results

In this section simulated results are compared with the naturalized flows from the TCEQ WAM for the Rio Grande (RJBCO, 2003) for the Pecos River control stations: GT2000 and GT1000. Statistical computations mentioned in previous section were also applied to interpret the results quantitatively. Results are presented separately for the Upper Basin and the Entire Basin in order to point out how different the geological structure is between the upper, from Red Bluff to Girvin, and lower Pecos River Basin, below Girvin. In addition, dates with 0 streamflows in the naturalized flows were set 0 in simulated streamflows as well. Negative values in naturalized flow calculation were changed to 0 values as mentioned in Chapter 2.

In general, the model represents the hydrological dynamics of the upper basin very well for both the calibration and validation periods. It can be inferred that the model can be used to make future predictions for the upper basin without any doubt. Hydrological representation of the entire basin by the model is not as perfect as the upper basin; however the model can be used to make future predictions for the entire basin with a wider range of probability of error. Ten-year monthly, annual and average monthly results for calibration period are respectively presented in Appendix J, K and L. Ten-year monthly, annual and average monthly results for validation period are respectively presented in Appendix M, N and O.

## 4.1 UPPER BASIN

### 4.1.1 Calibration Results

Simulated and naturalized streamflows are in a very good agreement for the calibration period in the upper basin. Especially, the streamflows in the first years and the peak flows in 1984 and 1986 were reproduced effectively (see Figure 39). Annual and average monthly streamflows also match with a high agreement (see Figure 40 and Figure 41).

Statistical results are shown in Table 28. In most months, the simulated and naturalized streamflows are very close with an error in volume of -6.6%. The negative error means that the model under estimates the flow. Error in volume less than 10%, within 10-20%, and within 20-30% can be considered as very good, good and fair performance respectively in hydrologic modeling. Therefore, a -6.6% error in volume indicates that the model has a very good performance. In addition, Index of Agreement indicates a significant agreement between simulated and naturalized streamflows with a value of 0.952. Nash coefficient has a value of 0.779 which means that the simulated results are a better indicator than the mean of the data (naturalized streamflow). Overall the correlation coefficient is 92% indicating a very good agreement between simulated and naturalized streamflows.

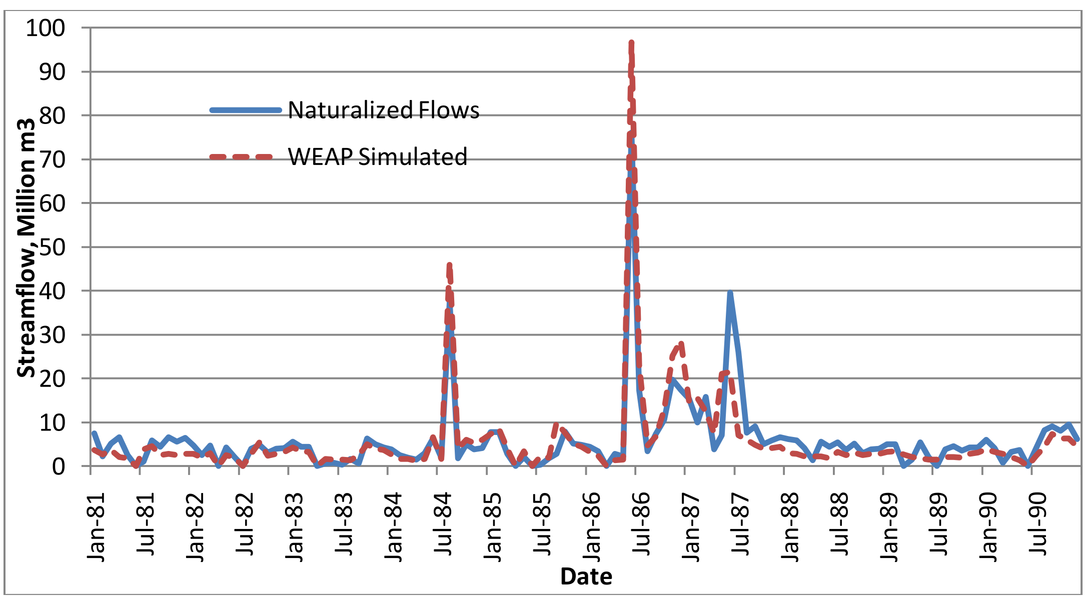


Figure 39: Monthly Simulated and Naturalized Streamflows in the Upper Basin for Calibration Period

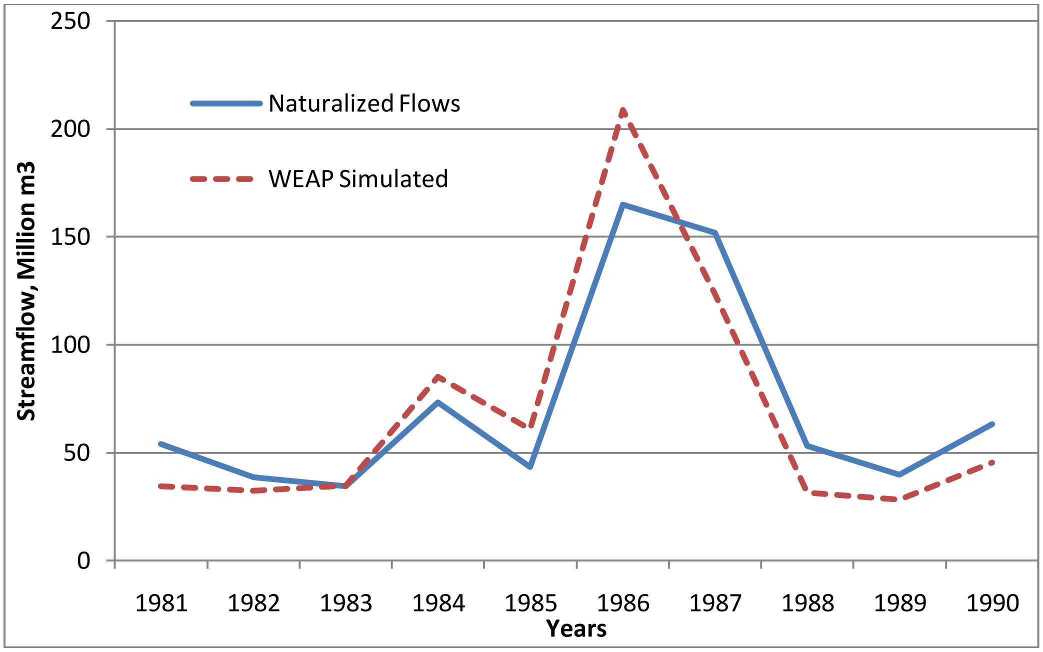


Figure 40: Annual Simulated and Naturalized Streamflows in the Upper Basin for Calibration Period

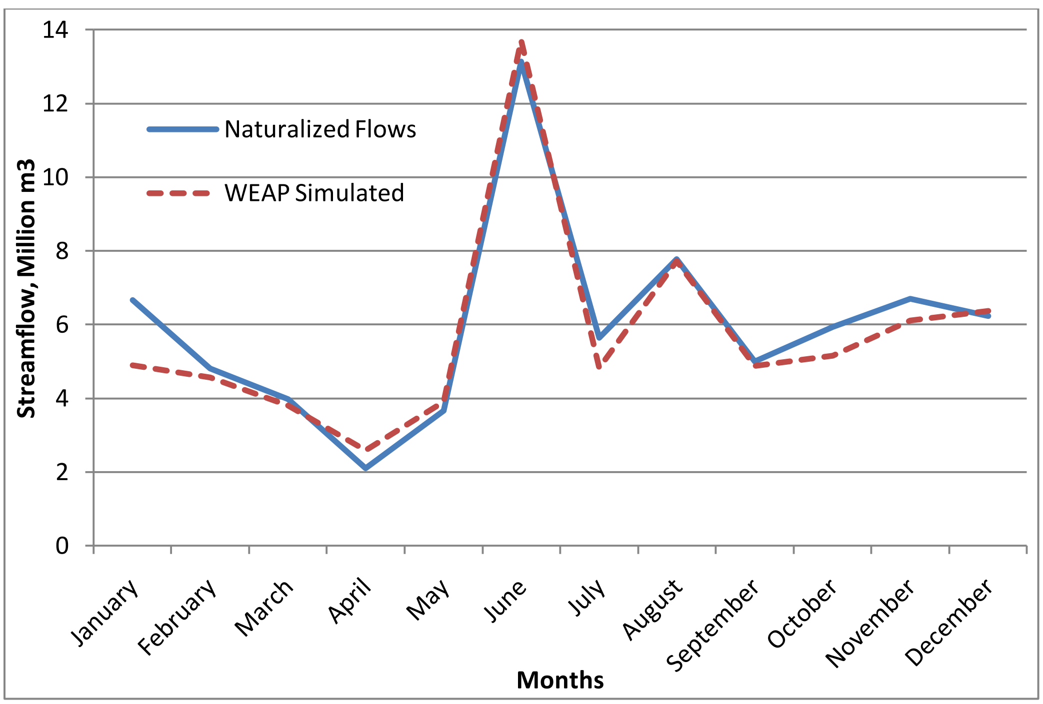


Figure 41: Average Monthly Simulated and Naturalized Streamflows in the Upper Basin for Calibration Period

| Measures | Naturalized | Simulated |
|---|---|---|
| Mean, $m^3$ | 5,970,723 | 5,576,448 |
| Median, $m^3$ | 4,246,858 | 2,911,389 |
| Standard Deviation, $m^3$ | 8,773,019 | 10,466,196 |
| Mean Absolute Error, $m^3$ | 2,307,541 | |
| Root Mean Square Error, $m^3$ | 4,106,877 | |
| Pearson's Correlation | 0.924 | |
| Coefficient of Determination | 0.853 | |
| Error in Volume, % | -6.6% | |
| | Average | Median |
| Index of Agreement (Willmott) | 0.952 | 0.954 |
| Modified Index of Agreement | 0.744 | 0.700 |
| Coefficient of Efficiency (Nash) | 0.779 | 0.787 |
| Modified Coefficient of Efficiency | 0.443 | 0.376 |

Table 28: Statistical Summary of the Model Results for the Upper Basin, Calibration Period

### 4.1.2 Validation Results

In order to validate the model, it was run for another 10-year time period between 1991 and 2000. Results for simulated and naturalized streamflows are in slightly better agreement than the calibration period. Both peak and base flows are reproduced effectively for the whole validation period (see Figure 42). Better results were obtained for annual streamflows compared to calibration results (see Figure 43), while monthly results are better in calibration period, Figure 44. The model has more errors in volume, especially in winter.

Statistical results are shown in Table 29. The error in volume for the validation period is less than the calibration period. In most months, the simulated and naturalized streamflows are very close with an error in volume of -3.7% which indicates the model has a very good performance. The Index of Agreement also shows a significant agreement between simulated and naturalized streamflows with a value of 0.953. A higher Nash coefficient was obtained in the validation period than the calibration period, 0.810. Overall, the correlation coefficient of 91% indicates a very good agreement between simulated and naturalized streamflows as well. In result, it can be inferred that the model reproduces streamflows with a higher agreement in the validation period than the calibration period.

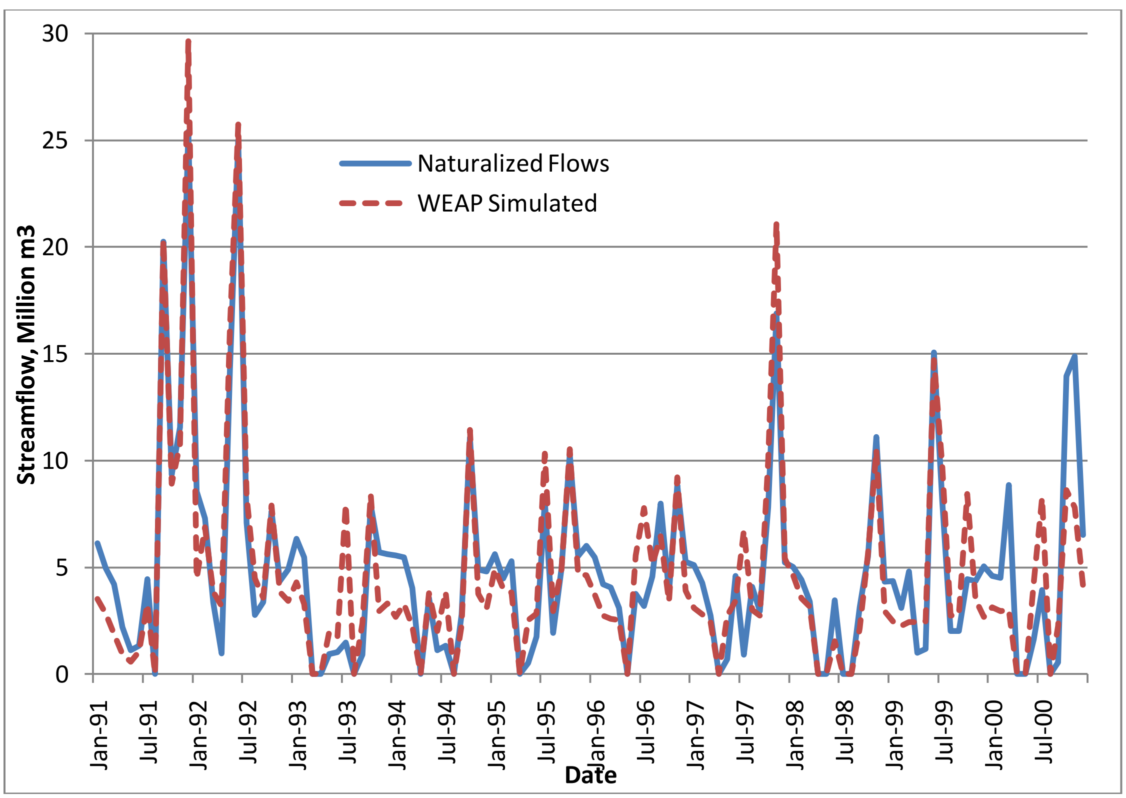


Figure 42: Monthly Simulated and Naturalized Streamflows in the Upper Basin for Validation Period

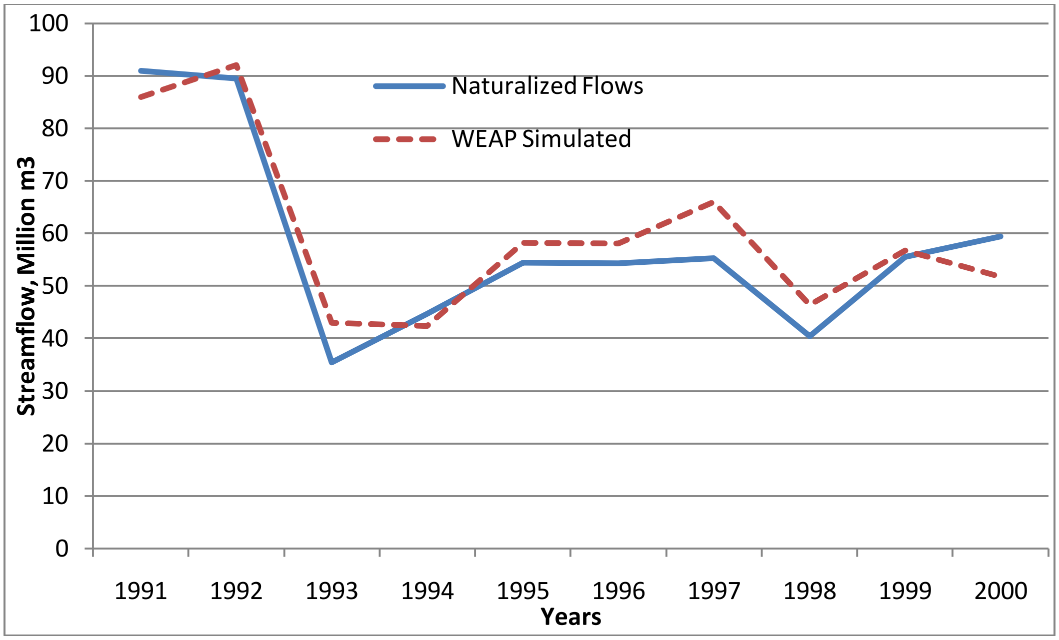


Figure 43: Annual Simulated and Naturalized Streamflows in the Upper Basin for Validation Period

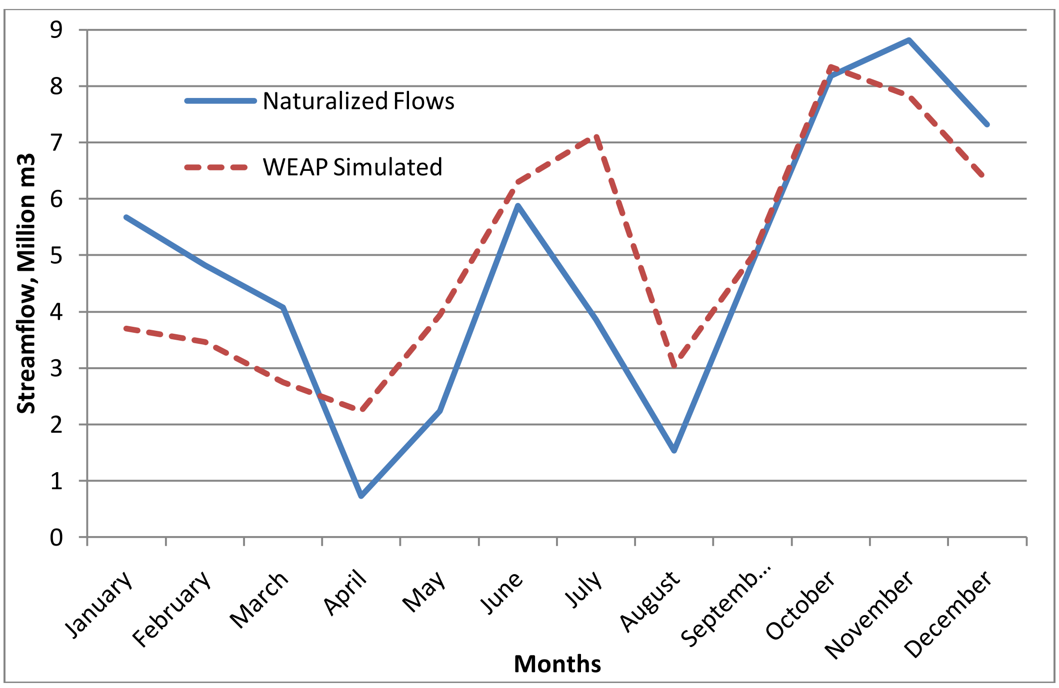


Figure 44: Average Monthly Simulated and Naturalized Streamflows in the Upper Basin for Validation Period

| Measures | Observed | Simulated |
|---|---|---|
| Mean, $m^3$ | 4,833,808 | 4,656,582 |
| Median, $m^3$ | 4,335,520 | 3,277,060 |
| Standard Deviation, $m^3$ | 4,658,415 | 4,865,246 |
| Mean Absolute Error, $m^3$ | 1,419,472 | |
| Root Mean Square Error, $m^3$ | 2,021,730 | |
| Pearson's Correlation | 0.911 | |
| Coefficient of Determination | 0.829 | |
| Error in Volume, % | -3.7% | |
| | Average | Median |
| Index of Agreement (Willmott) | 0.953 | 0.954 |
| Modified Index of Agreement | 0.777 | 0.767 |
| Coefficient of Efficiency (Nash) | 0.810 | 0.812 |
| Modified Coefficient of Efficiency | 0.541 | 0.531 |

Table 29: Statistical Summary of the Model Results for the Upper Basin, Calibration Period

## 4.2. ENTIRE BASIN

### 4.2.1 Calibration Results

The results for the entire basin are not as good as the results for the upper basin. Simulated and naturalized base flows are in a very good agreement; however the model cannot reproduce the peak flows very well. The model overestimates them, especially in 1987 (see Figure 45). The results are better for annual streamflows (see Figure 46). Monthly streamflows have a similar trend with naturalized flows except in July and October, Figure 47.

Statistical results are presented in Table 30. The model doesn't produce high errors in volume. It is even in the range of very good performance with a value of -5.8%; however, the overall correlation coefficient is 64%. This result can be considered fair comparing to many other hydrologic modeling cases such as Brent Frakes and Zhongbo Yu, 1999 and Arbind K. Verma, Madan K. Jha and Rajesh K. Mahana, 2009. The Index of Agreement indicates a sufficiently good agreement between simulated and naturalized streamflows with a value of 0.791. The model results are still a better indicator than the mean of naturalized streamflows with a value of 0.34 for the Nash coefficient. Even though the results for the entire basin are not as good as the results for the upper basin, the model still reproduces streamflows with good enough performance for many purposes including assessment of climate change impacts on the basin.

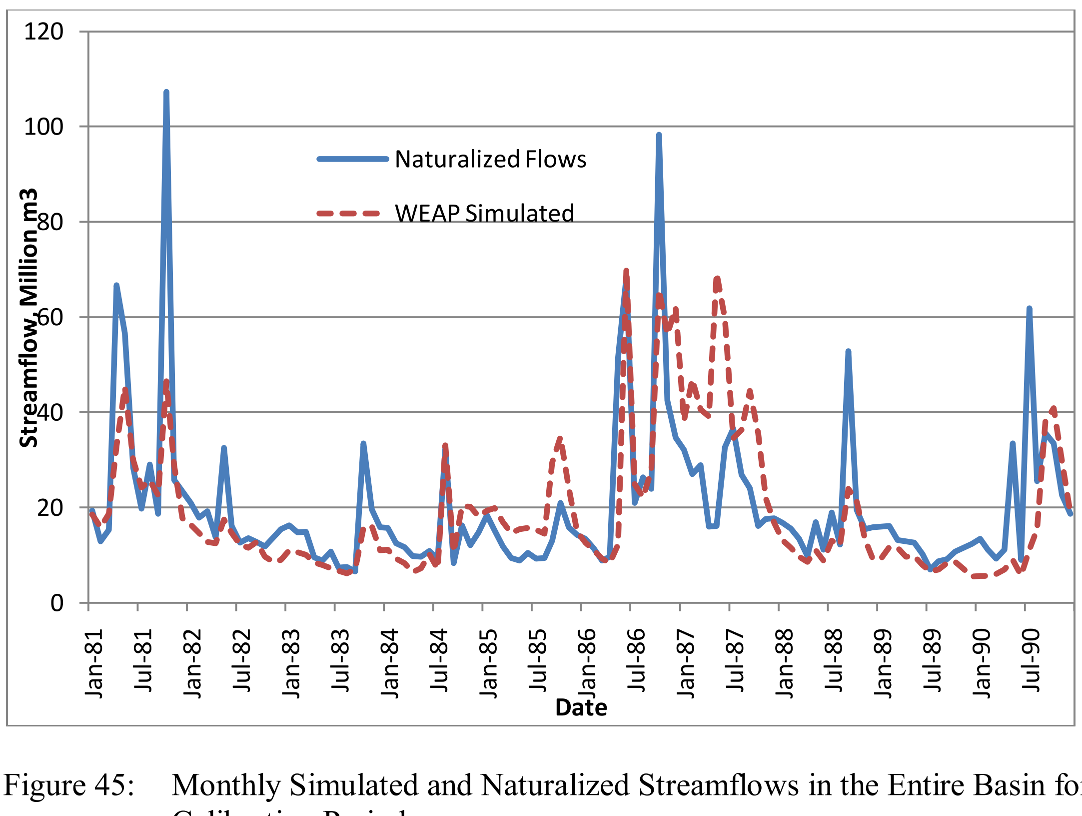


Figure 45: Monthly Simulated and Naturalized Streamflows in the Entire Basin for Calibration Period

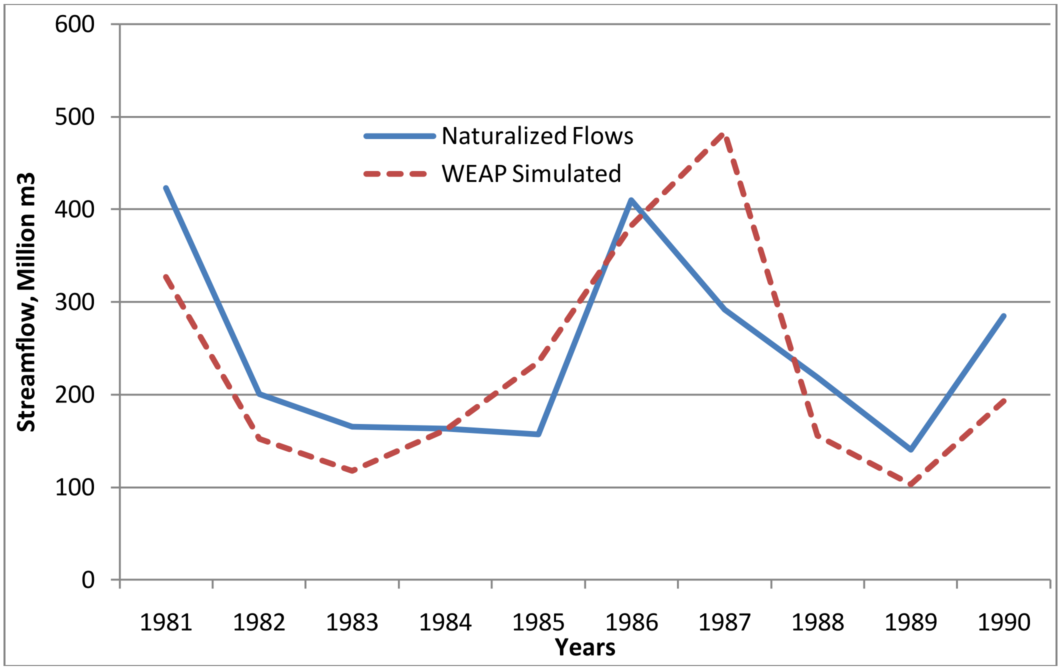


Figure 46: Annual Simulated and Naturalized Streamflows in the Entire Basin for Calibration Period

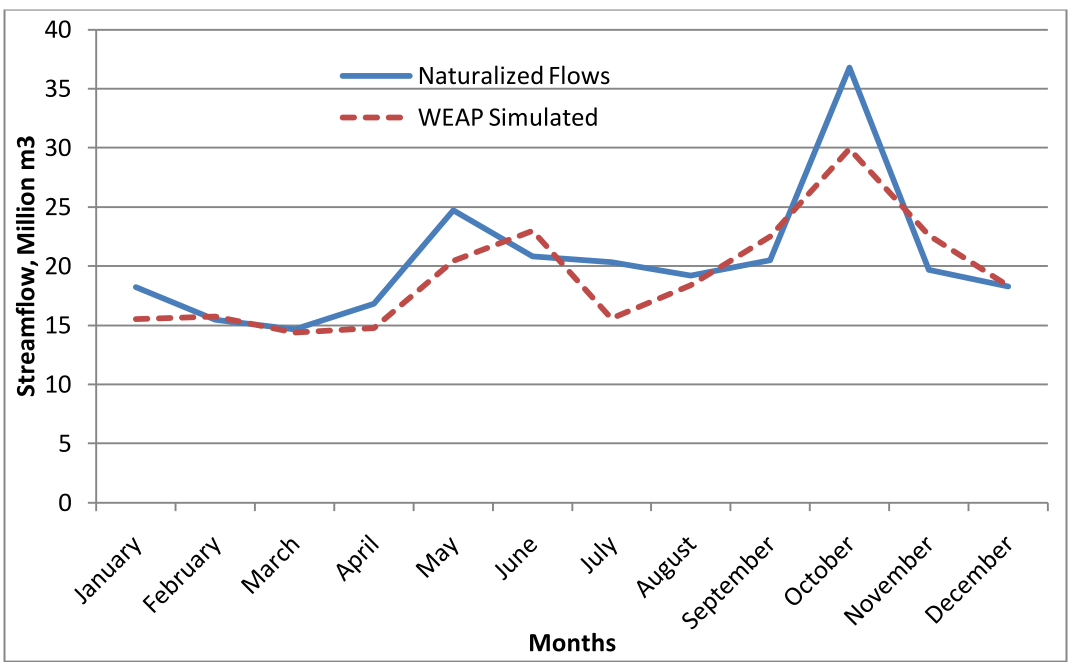


Figure 47: Average Monthly Simulated and Naturalized Streamflows in the Entire Basin for Calibration Period

| Measures | Observed | Simulated |
|---|---|---|
| Mean, $m^3$ | 20,458,186 | 19,265,913 |
| Median, $m^3$ | 15,638,143 | 13,899,071 |
| Standard Deviation, $m^3$ | 16,202,921 | 14,610,976 |
| Mean Absolute Error, $m^3$ | 7,541,569 | |
| Root Mean Square Error, $m^3$ | 13,108,361 | |
| Pearson's Correlation | 0.642 | |
| Coefficient of Determination | 0.413 | |
| Error in Volume, % | -5.8% | |
| | Average | Median |
| Index of Agreement (Willmott) | 0.791 | 0.801 |
| Modified Index of Agreement | 0.653 | 0.603 |
| Coefficient of Efficiency (Nash) | 0.340 | 0.394 |
| Modified Coefficient of Efficiency | 0.272 | 0.164 |

Table 30: Statistical Summary of the Model Results for the Entire Basin, Calibration Period

#### 4.2.2 Validation Results

In order to validate the model for the entire basin, it was run again with calibrated parameters from 1991 to 2000. Validation results have similar trends as the calibration results. The model reproduces base flow efficiently, while it cannot reproduce peak flows very well, Figure 48. Streamflow was overestimated especially in 1992, Figure 49. Average monthly streamflows are shown in Figure 50.

Statistical results for the validation period are similar to calibration period results, Table 31. During the validation period, streamflow reproduction increased. Error in volume increased from -5.8% to 1.5% which is still in the range of very good performance. On the other hand, the overall correlation coefficient provides a better representation for the model performance with a value of 62%. The Index of Agreement indicates a sufficiently good agreement between simulated and naturalized streamflows with a value of 0.781. The model results are still a better indicator than the mean of naturalized streamflows with a value of 0.228 for the Nash coefficient for the validation period as well. The model doesn't show any irregularities between calibration and validation period and it keeps the same level of performance for the validation period.

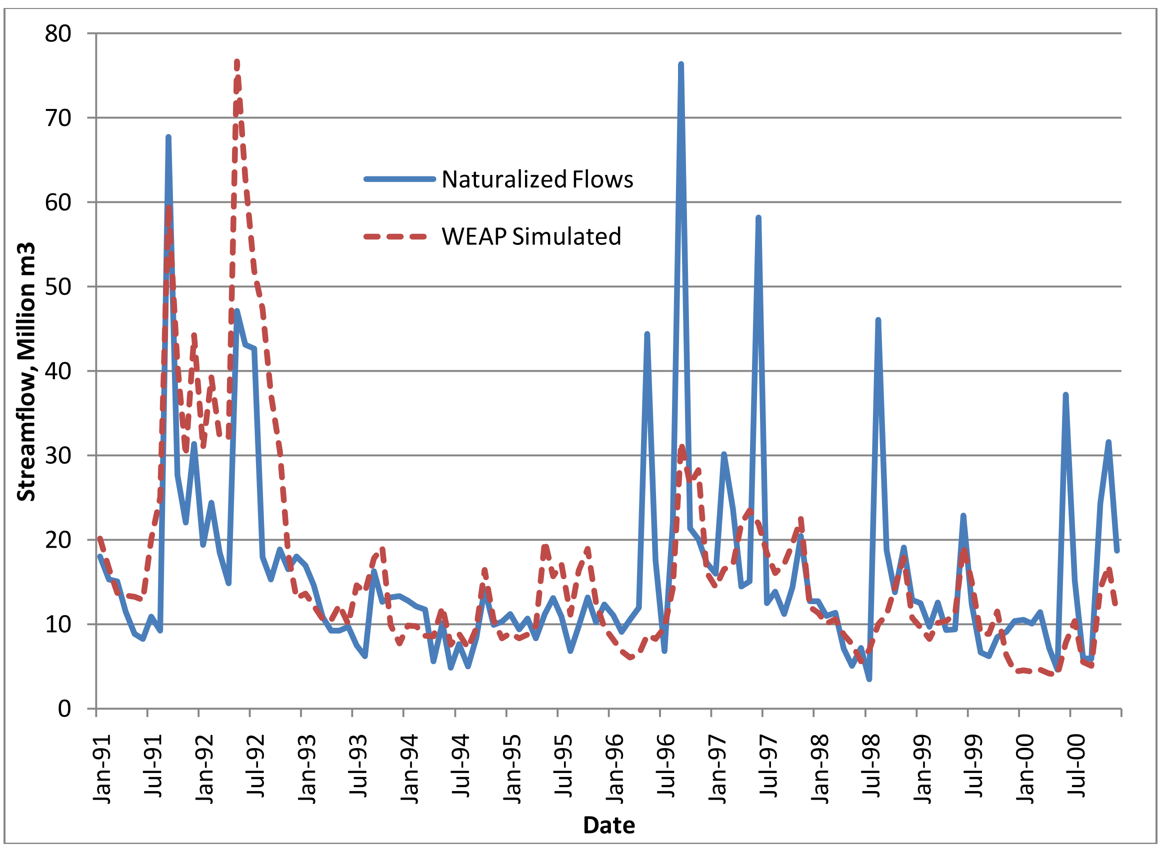


Figure 48: Monthly Simulated and Naturalized Streamflows in the Entire Basin for Validation Period

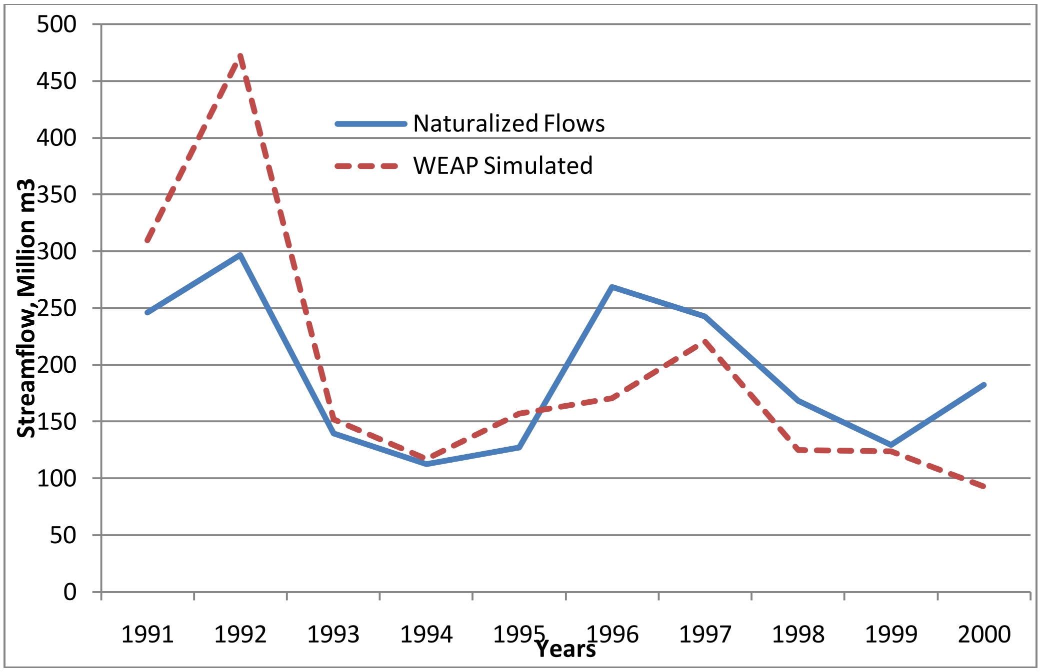


Figure 49: Annual Simulated and Naturalized Streamflows in the Entire Basin for Validation Period

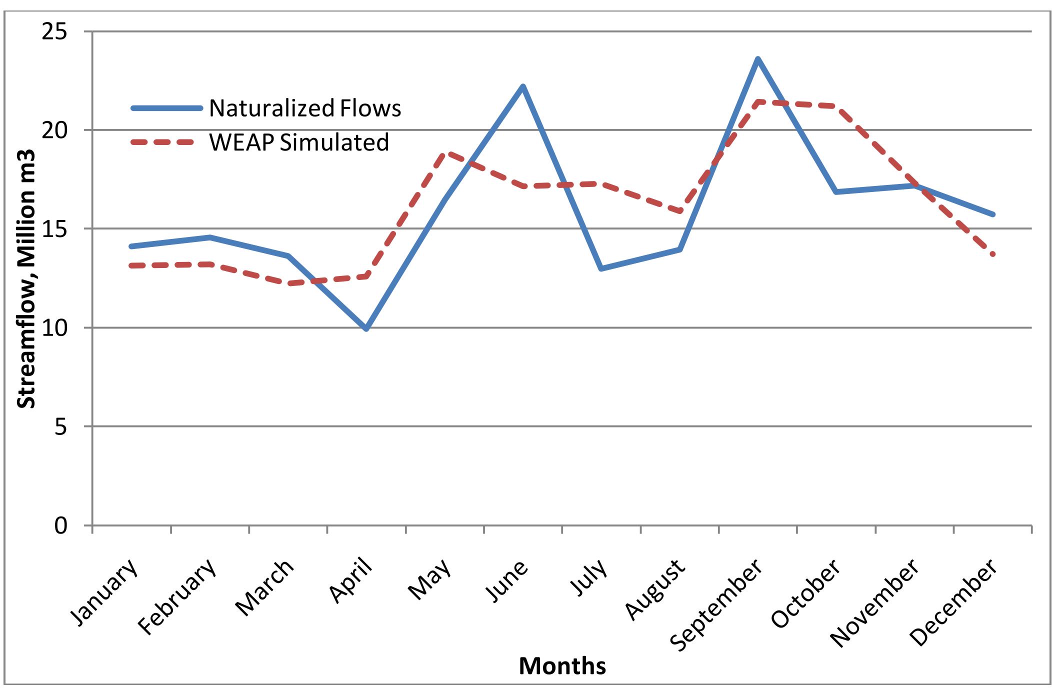


Figure 50: Average Monthly Simulated and Naturalized Streamflows in the Entire Basin for Validation Period

| Measures | Observed | Simulated |
| --- | --- | --- |
| Mean, $m^3$ | 15,932,928 | 16,167,274 |
| Median, $m^3$ | 12,487,184 | 12,091,556 |
| Standard Deviation, $m^3$ | 12,052,434 | 12,351,543 |
| Mean Absolute Error, $m^3$ | 6,589,127 | |
| Root Mean Square Error, $m^3$ | 10,545,552 | |
| Pearson's Correlation | 0.624 | |
| Coefficient of Determination | 0.389 | |
| Error in Volume, % | 1.5% | |
| | Average | Median |
| Index of Agreement (Willmott) | 0.781 | 0.797 |
| Modified Index of Agreement | 0.586 | 0.545 |
| Coefficient of Efficiency (Nash) | 0.228 | 0.287 |
| Modified Coefficient of Efficiency | 0.146 | 0.044 |

Table 31: Statistical Summary of the Model Results for the Entire Basin, Validation Period

# Chapter 5: Conclusions

Since this project is the first and only academic study on hydrologic modeling of the Pecos River Basin, it provides an exemplary work for future researches. The hydrological model constructed in WEAP simulates streamflows very well in the upper basin. However, the model results for the GT1000 (Pecos R nr Langtry, TX) control gage are not as good as the results for the upper basin, GT2000. While the simulated base flows are in a good agreement with naturalized streamflows for the GT1000 control gage, peak flows cannot be reproduced very well. Differences in the geological structures between upper basin, from Red Bluff to Girvin, and lower basin, below Girvin, may cause this problem. The upper Pecos floodplain is broad with very deep aquifer sediments. The lower Pecos is mainly fractured limestone with bedrock channel so flow conditions are flashier in the lower Pecos. Shallow aquifers, tributary inflows and especially groundwater contribution can be considered as possible causes of flashier flow conditions in the lower Pecos. Due to complex nature of the geological structure in the lower basin, representation of hydrological dynamics of the Pecos River Basin is a difficult duty. In spite of everything, Results for the GT1000 control gage can be considered fair comparing to many other hydrologic modeling cases such as Brent Frakes and Zhongbo Yu, 1999 and Arbind K. Verma, Madan K. Jha and Rajesh K. Mahana, 2009. Another difficulty for hydrologic modeling of the basin is that there are only two control gages for the entire basin: GT2000 controls the flows form Red Bluff to Girvin and GT1000 controls the flows for entire basin. Considering the flashier flows in the lower basin, a small error may accumulate and cause big differences at the outlet. If the basin had had more control gages, calibration of the simulated flows might have done easier.

Uncertainties and assumptions in the naturalized flow calculations are also another factor affecting model performance. Pecos River Basin was mentioned as the most problematic basin in the WAM report. Several irregularities were indicated for the Pecos River Basin. Lack of information on groundwater interaction, water supplies in Balmorhea Reservoir, irrigation diversions and return flows are the main uncertainties in the naturalized flow calculations. The non-static occurrence and density of salt cedar along the Pecos River Basin is certainly another uncertainty. More information is provided under The Pecos River and Naturalized Streamflow Data sections in Chapter 2.

After the first run of the calibration process, NARR precipitation data was compared with TWBD precipitation data in order to determine whether NARR provides a good representation of precipitation or not. Both data sets match with high agreement R2= 0.97; however, another sign of inappropriateness was noticed in the naturalized streamflows. Simulated streamflows respond to precipitation pulses better than naturalized streamflows in the lower basin. Simulated and naturalized streamflows show a big difference at the GT1000 gage station in 1987 and 1992. High precipitation occurred in the lower basin in these years and simulated streamflows provide a better response than naturalized streamflows.

Another important factors affect the hydrologic modeling process are the validity and usability of the various data sources used in this research. Since all the data used in this research were obtained from reliable institutions, validity of the data sources is not an issue. However, the usability and quality of the data varies depending on the representation of the data.

Three data sources were evaluated for the climate data. From these three data source, the NARR data source is the only one which contains all required climate parameters for the study period. The NARR data source also provides the highest resolution data for the study period. The dataset contains 32-km spatial and 3-hour analyses of North America, adjacent oceans and land masses from October 1978 to present (NCEP, 2004). On the other hand, the TWBD data source contains only precipitation and evaporation data just for Texas. The data are presented in one degree quadrangles which is not as good as the NARR data. Another data source is the NCDC climate stations. Since these stations directly measure climatic parameters at one point, they are represented as point source data. The NCDC data couldn't be used in this project, because there are not enough stations with complete data for the required time period. In terms of usability and quality, the NARR data source is the best available data source for climate data for the study period.

Five different data sources were evaluated for the soil data: FAO, NATSGO, STATSGO, SSURGO and NLDAS. From these five data source, NLDAS data source provides the most usable data. It is also a combination of other data sources. This data set was derived from STATSGO and 5 minute FAO data by National Oceanic and Atmospheric Administration (NOAA) within the scope of the North American Land Data Assimilation System (NLDAS, 2008). During this research attributes table of the FAO soil map was not available and the NATSGO soil map is still under construction. Processing the remaining data sources, STATASGO and SSURGO, are almost impossible due to their complex representation. More information is provided under Soil Data section in Chapter 2.

Since the calibration process was repeated carefully three times by Sedat Yalcinkaya and controlled by Eusebio Ingol Blanco in CRWR and results were examined by another group of researchers from Texas A&M University, further optimization of the calibration parameters will not provide significant improvements in the simulated streamflows. Everyone is in agreement that lower results were obtained for the lower basin because of the complex nature of the geological structure in the lower Pecos River Basin.

Temperature and precipitation data from 1981 to 2000 indicates a $1^0$C increase in temperature and 100 mm decrease in precipitation over the basin. Considering the increasing water demand and huge amount of non-agricultural water consumption by salt cedar, analyzing climate change effects on water resources in the basin is necessary. This project can be a good source for further researches to assess climate change effects under different climate change scenarios in the basin, especially between Red Bluff Reservoir and Girvin.

# Appendix A: NCDC Stations' Names and Location in the Pecos River Basin

| NO | STATION_NAME | LATITUDE,DD | LONGITUDE, DD |
|---|---|---|---|
| 1 | ALPINE | 30.37 | -103.65 |
| 2 | BAKERSFIELD | 30.88 | -102.30 |
| 3 | BAKERSFIELD 11 SSE | 30.72 | -102.22 |
| 4 | BALMORHEA | 30.98 | -103.73 |
| 5 | BALMORHEA WB PAN | 31.00 | -103.68 |
| 6 | BALMORHEA CIRCLE H RCH | 30.85 | -103.98 |
| 7 | BALMORHEA | 30.98 | -103.73 |
| 8 | BALMORHEA GRAEF RCH | 30.93 | -103.52 |
| 9 | BUENAVISTA 2 NNW | 31.25 | -102.67 |
| 10 | CHANCELLOR | 30.70 | -103.18 |
| 11 | CHILDRESS RCH | 31.00 | -104.03 |
| 12 | COMSTOCK 11 WNW | 29.70 | -101.35 |
| 13 | CRANE | 31.38 | -102.35 |
| 14 | CRANE 10N | 31.67 | -102.40 |
| 15 | DRYDEN 10 NE | 30.20 | -101.83 |
| 16 | FT DAVIS | 30.60 | -103.88 |
| 17 | FT STOCKTON 1 | 30.88 | -102.88 |
| 18 | FT STOCKTON | 30.90 | -102.90 |
| 19 | GIRVIN | 31.07 | -102.40 |
| 20 | GRANDFALLS 3SSE | 31.30 | -102.82 |
| 21 | IMPERIAL | 31.27 | -102.70 |
| 22 | JUDKINS | 31.72 | -102.63 |
| 23 | KENT 5 E | 31.07 | -104.15 |
| 24 | KENT 8SE | 31.02 | -104.10 |
| 25 | KINGSTON RCH | 30.87 | -103.98 |
| 26 | MCCAMEY | 31.13 | -102.22 |
| 27 | MENTONE 2 S | 31.68 | -103.60 |
| 28 | MONAHANS | 31.53 | -102.90 |
| 29 | MONAHANS 1 NW | 31.60 | -102.90 |
| 30 | MT LOCKE | 30.70 | -104.02 |

| NO | STATION_NAME | LATITUDE,DD | LONGITUDE, DD |
|---|---|---|---|
| 31 | OZONA 8 WSW | 30.67 | -101.33 |
| 32 | PANDALE 1 N | 30.20 | -101.55 |
| 33 | PANDALE 11 NE | 30.27 | -101.45 |
| 34 | PECOS | 31.42 | -103.50 |
| 35 | PECOS 8W | 31.37 | -103.62 |
| 36 | PENWELL | 31.73 | -102.58 |
| 37 | POPHAM RCH | 30.88 | -103.55 |
| 38 | PREWIT RCH | 31.28 | -103.50 |
| 39 | RANKIN | 31.22 | -101.93 |
| 40 | RED BLUFF DAM | 31.88 | -103.92 |
| 41 | SHEFFIELD | 30.68 | -101.82 |
| 42 | TINNIN RCH | 31.32 | -103.98 |
| 43 | TOYAH | 31.30 | -103.80 |
| 44 | WINKLER CO AP | 31.77 | -103.20 |
| 45 | HOBBS 13W | 32.70 | -103.35 |
| 46 | JAL | 32.10 | -103.18 |
| 47 | OCHOA | 32.15 | -103.42 |
| 48 | PEARL | 32.65 | -103.38 |

# Appendix B: NLDAS Soil Layers and Textures

The soil datasets layers are:

| Layer | Thickness | Depth to Top | Depth to Bottom |
|---|---|---|---|
| 1 | 5 cm (2 in) | 0 cm (0 in) | 5 cm (2 in) |
| 2 | 5 cm (2 in) | 5 cm (2 in) | 10 cm (4 in) |
| 3 | 10 cm (4 in) | 10 cm (4 in) | 20 cm (8 in) |
| 4 | 10 cm (4 in) | 20 cm (8 in) | 30 cm (12 in) |
| 5 | 10 cm (4 in) | 30 cm (12 in) | 40 cm (16 in) |
| 6 | 20 cm (8 in) | 40 cm (16 in) | 60 cm (24 in) |
| 7 | 20 cm (8 in) | 60 cm (24 in) | 80 cm (31 in) |
| 8 | 20 cm (8 in) | 80 cm (31 in) | 100 cm (39 in) |
| 9 | 50 cm (20 in) | 100 cm (39 in) | 150 cm (59 in) |
| 10 | 50 cm (20 in) | 150 cm (59 in) | 200 cm (79 in) |
| 11 | 50 cm (20 in) | 200 cm (79 in) | 250 cm (98 in) |

The soil datasets texture classification definitions are:

| | | |
|---|---|---|
| 1 | S | Sand |
| 2 | LS | Loamy sand |
| 3 | SL | Sandy loam |
| 4 | SIL | Silt loam |
| 5 | SI | Silt |
| 6 | L | Loam |
| 7 | SCL | Sandy clay loam |
| 8 | SICL | Silty clay loam |
| 9 | CL | Clay loam |
| 10 | SC | Sandy clay |
| 11 | SIC | Silty clay |
| 12 | C | Clay |
| 13 | OM | Organic materials |
| 14 | W | Water |
| 15 | BR | Bedrock |
| 16 | O | Other |

# Appendix C: UMD Vegetation Types

| Category | UMD Vegetation Type |
|---|---|
| Category 0 | Frequency of Water (And Goode's Interrupted Space) |
| Category 1 | Frequency of Evergreen Needleleaf Forest |
| Category 2 | Frequency of Evergreen Broadleaf Forest |
| Category 3 | Frequency of Deciduous Needleleaf Forest |
| Category 4 | Frequency of Deciduous Broadleaf Forest |
| Category 5 | Frequency of Mixed Cover |
| Category 6 | Frequency of Woodland |
| Category 7 | Frequency of Wooded Grassland |
| Category 8 | Frequency of Closed Shrubland |
| Category 9 | Frequency of Open Shrubland |
| Category 10 | Frequency of Grassland |
| Category 11 | Frequency of Cropland |
| Category 12 | Frequency of Bare Ground |
| Category 13 | Frequency of Urban and Built-Up |

# Appendix D: NLCD Vegetation Classes

Water

11. Open Water
12. Perennial Ice/Snow

Developed

21. Developed, Open Space
22. Developed, Low Intensity
23. Developed, Medium Intensity
24. Developed, High Intensity

Barren

31. Barren Land (Rock/Sand/Clay)
32. Unconsolidated Shore*

Vegetated; Natural Forested Upland

41. Deciduous Forest
42. Evergreen Forest

Vegetated; Natural Shrubland

51. Dwarf Scrub
52. Shrub/Scrub

Herbaceous Upland Natural/Seminatural Vegetation

71. Grassland/Herbaceous
72. Sedge/Herbaceous
73. Lichens
74. Moss

Herbaceous Planted/Cultivated

81. Pasture/Hay
82. Cultivated Crops

Wetlands

90. Woody Wetlands
91. Palustrine Forested Wetland*
92. Palustrine Scrub/Shrub Wetland*
93. Estuarine Forested Wetland*
94. Estuarine Scrub/Shrub Wetland*
95. Emergent Herbaceous Wetlands
96. Palustrine Emergent Wetland (Persistent)*
97. Estuarine Emergent Wetland*
98. Palustrine Aquatic Bed*
99. Estuarine Aquatic Bed*

*Coastal NLCD class only

# Appendix E: NARR Monthly Precipitation Data

NARR monthly precipitation data in mm

| Date | Watershed | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 13070001 | 13070003 | 13070004 | 13070005 | 13070006 | 13070007 | 13070008 | 13070009 | 13070010 | 13070011 |
| Jan-81 | 26.03678 | 29.853 | 29.20721 | 25.33221 | 32.59786 | 17.93439 | 31.38688 | 39.86327 | 38.89458 | 30.66024 |
| Feb-81 | 9.36488 | 11.80426 | 10.05426 | 10.6376 | 8.887603 | 11.27396 | 9.762614 | 8.450109 | 9.762614 | 9.762614 |
| Mar-81 | 16.71505 | 22.76241 | 20.17907 | 23.40822 | 27.76757 | 11.78322 | 31.64257 | 28.25191 | 32.12691 | 43.75191 |
| Apr-81 | 47.85792 | 53.88072 | 44.19312 | 48.88056 | 61.53696 | 53.82384 | 92.94312 | 70.44312 | 102.3182 | 120.5993 |
| May-81 | 41.35574 | 47.93146 | 37.27514 | 35.01487 | 43.73356 | 43.11703 | 80.06159 | 67.95225 | 86.35856 | 107.1866 |
| Jun-81 | 28.45296 | 22.03241 | 46.09488 | 39.53232 | 24.0636 | 27.08928 | 46.79808 | 26.40744 | 25.47 | 52.65744 |
| Jul-81 | 71.20055 | 55.58325 | 66.23931 | 87.22904 | 70.76035 | 56.93361 | 17.96336 | 49.44773 | 32.01035 | 14.08836 |
| Aug-81 | 51.13388 | 65.92956 | 67.22114 | 98.86694 | 75.13259 | 52.54302 | 48.24989 | 50.42956 | 44.61694 | 49.46062 |
| Sep-81 | 54.1188 | 78.20952 | 71.6472 | 75.08472 | 61.02216 | 52.75512 | 13.20962 | 29.61576 | 10.39711 | 16.49088 |
| Oct-81 | 74.03618 | 67.22561 | 53.98588 | 71.7464 | 92.09009 | 86.36575 | 129.8714 | 124.059 | 144.4027 | 146.3401 |
| Nov-81 | 0.095132 | 0.095132 | 0.095132 | 0.095132 | 0.095132 | 1.629223 | 0.329508 | 0.095132 | 0.095132 | 1.501382 |
| Dec-81 | 0.109775 | 0.109775 | 0.109775 | 0.109775 | 0.109775 | 0.638183 | 0.109775 | 0.109775 | 0.109775 | 0.109775 |
| Jan-82 | 3.502727 | 3.385299 | 5.968641 | 5.968641 | 3.546772 | 4.735684 | 10.08584 | 3.546772 | 9.843641 | 11.29677 |
| Feb-82 | 1.541317 | 1.276166 | 1.567832 | 3.609491 | 3.609491 | 2.336768 | 12.14076 | 3.609491 | 6.234502 | 20.2345 |
| Mar-82 | 1.207574 | 0.150755 | 0.473673 | 0.150755 | 0.150755 | 4.730302 | 1.119504 | 0.150755 | 0.150755 | 2.088254 |
| Apr-82 | 21.39737 | 18.21557 | 20.71555 | 15.09055 | 20.24681 | 23.27237 | 31.49688 | 29.62176 | 40.40304 | 30.5592 |
| May-82 | 51.0322 | 48.56634 | 42.75371 | 54.37871 | 54.86306 | 72.34458 | 65.76166 | 51.4724 | 49.53502 | 85.86306 |
| Jun-82 | 43.22424 | 58.8492 | 48.84912 | 50.72424 | 59.6304 | 34.53096 | 43.69296 | 53.06784 | 40.41168 | 54.00528 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Jul-82 | 47.11554 | 33.67046 | 56.59732 | 60.14942 | 48.04008 | 43.41662 | 17.04015 | 37.38402 | 30.11836 | 12.68076 |
| Aug-82 | 19.08382 | 23.31108 | 23.31108 | 34.93601 | 29.60798 | 21.19745 | 22.34234 | 22.82671 | 22.34234 | 26.21732 |
| Sep-82 | 15.59412 | 10.08276 | 18.52025 | 15.08275 | 9.457752 | 21.73049 | 13.20775 | 7.114008 | 9.457752 | 13.20775 |
| Oct-82 | 5.684458 | 1.9856 | 3.600191 | 3.923087 | 3.923087 | 6.036742 | 9.735587 | 7.313718 | 10.70435 | 18.45435 |
| Nov-82 | 20.88154 | 23.2111 | 22.89859 | 20.71109 | 20.24234 | 24.80208 | 25.63296 | 18.36734 | 24.46104 | 26.80488 |
| Dec-82 | 36.91902 | 40.14798 | 43.05429 | 44.66902 | 36.43442 | 38.68031 | 36.67672 | 33.04402 | 43.70008 | 35.46574 |
| Jan-83 | 15.96708 | 19.4898 | 17.87522 | 25.3022 | 20.45856 | 19.13754 | 22.15386 | 14.16167 | 18.52106 | 32.08351 |
| Feb-83 | 4.578493 | 5.373939 | 4.20728 | 12.37394 | 8.436445 | 7.919408 | 15.43644 | 5.811456 | 14.99895 | 19.81146 |
| Mar-83 | 2.643754 | 4.052841 | 5.021578 | 9.865341 | 5.990341 | 2.643754 | 8.896578 | 5.505972 | 8.896578 | 16.16221 |
| Apr-83 | 10.59581 | 8.948088 | 15.19807 | 7.698072 | 4.885584 | 8.720808 | 3.948072 | 2.073079 | 3.948072 | 6.29184 |
| May-83 | 14.96757 | 16.31793 | 8.89085 | 19.54711 | 21.00022 | 27.64927 | 24.39085 | 21.96898 | 28.2658 | 31.17211 |
| Jun-83 | 15.18218 | 17.05718 | 14.5572 | 41.43216 | 21.7447 | 19.10266 | 42.3696 | 19.40095 | 33.93216 | 63.93216 |
| Jul-83 | 7.885011 | 15.63501 | 17.57251 | 36.94754 | 18.54125 | 8.589554 | 14.18188 | 5.947511 | 6.916249 | 23.86938 |
| Aug-83 | 7.482086 | 5.251028 | 4.605186 | 15.58434 | 9.771845 | 9.067302 | 16.55311 | 5.412476 | 10.74061 | 27.69366 |
| Sep-83 | 29.37384 | 45.05568 | 32.86824 | 63.80568 | 46.46184 | 31.76016 | 10.60258 | 16.9307 | 12.24322 | 7.555704 |
| Oct-83 | 64.34658 | 67.86942 | 59.15048 | 87.24442 | 74.65048 | 69.63071 | 101.5334 | 95.47876 | 101.7755 | 118.2444 |
| Nov-83 | 15.49426 | 10.77835 | 7.340832 | 13.27834 | 14.21585 | 26.23296 | 24.76272 | 22.18459 | 24.52824 | 28.7472 |
| Dec-83 | 3.08321 | 3.318042 | 1.703465 | 2.026381 | 2.026381 | 3.963883 | 0.573257 | 1.542007 | 0.088881 | 0.088881 |
| Jan-84 | 7.318158 | 9.13823 | 9.46115 | 13.65905 | 11.23718 | 6.43746 | 21.65124 | 16.08094 | 22.37781 | 31.09647 |
| Feb-84 | 0.738084 | 0.101721 | 0.101721 | 0.101721 | 0.101721 | 1.056265 | 2.289213 | 1.851721 | 1.851721 | 1.851721 |
| Mar-84 | 0.289892 | 0.113757 | 0.436673 | 0.113757 | 0.598131 | 0.113757 | 3.746561 | 0.113757 | 2.051258 | 12.7075 |
| Apr-84 | 0.1738 | 0.1738 | 0.1738 | 0.1738 | 0.1738 | 0.1738 | 0.408175 | 0.1738 | 0.1738 | 1.58005 |
| May-84 | 60.76967 | 45.38698 | 44.74118 | 36.99118 | 50.06922 | 84.37183 | 33.11618 | 57.33487 | 38.92856 | 26.81922 |
| Jun-84 | 70.0524 | 110.166 | 76.72848 | 163.291 | 115.4784 | 76.87056 | 47.50968 | 56.41584 | 47.9784 | 48.44712 |
| Jul-84 | 15.39458 | 22.02905 | 20.09155 | 52.3833 | 33.49265 | 18.56503 | 21.8676 | 17.5082 | 18.47697 | 23.8051 |
| Aug-84 | 59.56266 | 51.69535 | 69.45587 | 63.96614 | 42.65377 | 74.18201 | 15.52867 | 11.65367 | 10.68493 | 20.37243 |
| Sep-84 | 35.82216 | 40.02672 | 30.96432 | 31.90176 | 52.9956 | 28.8336 | 49.01112 | 66.12048 | 52.52688 | 45.02688 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Oct-84 | 67.19659 | 68.54695 | 67.57826 | 91.15116 | 83.40116 | 70.01486 | 77.34649 | 95.02616 | 98.90116 | 77.58878 |
| Nov-84 | 22.08602 | 28.84728 | 18.53489 | 35.72232 | 32.44104 | 34.35864 | 36.42552 | 31.03488 | 31.97232 | 39.0036 |
| Dec-84 | 26.67959 | 38.18729 | 34.63518 | 46.58308 | 31.56742 | 30.73092 | 33.98939 | 28.17677 | 33.0207 | 36.41111 |
| Jan-85 | 15.59364 | 22.6978 | 18.8228 | 27.21874 | 26.24981 | 11.54252 | 18.49988 | 23.82801 | 19.46864 | 23.82801 |
| Feb-85 | 13.15881 | 12.36334 | 10.61334 | 12.36334 | 13.67585 | 16.65881 | 20.23836 | 18.48836 | 21.11334 | 21.11334 |
| Mar-85 | 8.241139 | 8.534722 | 7.243038 | 9.82638 | 7.88888 | 10.70705 | 17.33418 | 9.342011 | 13.70138 | 27.74822 |
| Apr-85 | 9.816768 | 14.47586 | 13.85086 | 11.35087 | 11.35087 | 9.816768 | 12.99149 | 8.069616 | 7.600872 | 23.53836 |
| May-85 | 20.20429 | 17.56224 | 17.88514 | 23.37474 | 28.21843 | 27.07366 | 32.57778 | 27.24974 | 31.12474 | 48.07778 |
| Jun-85 | 52.9812 | 36.39024 | 33.2652 | 47.01528 | 52.17144 | 67.81056 | 62.71824 | 56.39016 | 52.64016 | 86.85888 |
| Jul-85 | 38.33981 | 55.65988 | 48.23278 | 77.6183 | 61.14936 | 43.27154 | 38.626 | 41.77436 | 34.02436 | 39.35264 |
| Aug-85 | 17.65001 | 23.28638 | 21.02596 | 42.66146 | 29.09883 | 22.40571 | 32.48949 | 38.30211 | 42.66146 | 21.34888 |
| Sep-85 | 69.73728 | 65.64624 | 64.7088 | 93.77136 | 79.7088 | 91.2144 | 87.44328 | 63.30264 | 58.14624 | 104.5526 |
| Oct-85 | 71.0277 | 56.23226 | 58.81543 | 38.79464 | 42.66964 | 84.59007 | 59.62267 | 58.16964 | 51.38833 | 64.95095 |
| Nov-85 | 12.17016 | 10.69289 | 8.19288 | 7.567896 | 8.03664 | 13.1929 | 12.02102 | 8.505384 | 8.505384 | 17.41164 |
| Dec-85 | 0.073627 | 0.073627 | 0.073627 | 0.073627 | 0.073627 | 0.073627 | 0.073627 | 0.073627 | 0.073627 | 0.073627 |
| Jan-86 | 6.781486 | 7.192471 | 3.963313 | 5.900813 | 10.26018 | 4.315572 | 5.658616 | 9.291444 | 5.900813 | 7.353944 |
| Feb-86 | 6.330621 | 4.792749 | 6.251078 | 3.62609 | 5.813584 | 6.807898 | 10.40733 | 9.313584 | 15.00108 | 11.9386 |
| Mar-86 | 0.858244 | 2.091198 | 1.768282 | 4.02871 | 2.091198 | 1.034381 | 2.091198 | 1.122448 | 1.122448 | 3.544317 |
| Apr-86 | 4.583976 | 2.652168 | 1.402166 | 2.027167 | 4.370928 | 4.583976 | 16.7928 | 21.71467 | 31.0896 | 12.80842 |
| May-86 | 42.94988 | 53.10697 | 40.83618 | 48.58618 | 48.58618 | 60.21118 | 79.10183 | 41.32052 | 46.64855 | 106.2268 |
| Jun-86 | 98.01 | 78.294 | 87.35664 | 122.0441 | 90.1692 | 112.8396 | 72.35664 | 78.9192 | 66.73152 | 68.13792 |
| Jul-86 | 36.97035 | 51.17877 | 46.98087 | 44.72035 | 29.22035 | 40.31711 | 17.59548 | 14.68921 | 11.78298 | 18.56421 |
| Aug-86 | 78.29707 | 67.25934 | 58.54065 | 91.15513 | 97.93644 | 93.0925 | 90.67078 | 108.1082 | 70.81144 | 96.9675 |
| Sep-86 | 67.0128 | 83.77416 | 65.33664 | 84.39912 | 88.61784 | 87.80832 | 50.41488 | 56.74296 | 29.08656 | 35.1804 |
| Oct-86 | 84.24585 | 82.07362 | 75.9381 | 91.1152 | 85.78717 | 84.06977 | 155.5372 | 122.1152 | 141.4902 | 178.7872 |
| Nov-86 | 33.14328 | 30.70008 | 31.01256 | 22.57505 | 20.2313 | 42.8592 | 22.34069 | 19.76256 | 29.13744 | 24.45 |
| Dec-86 | 76.539 | 83.40835 | 73.07518 | 75.65835 | 73.23663 | 78.30054 | 67.18196 | 74.20532 | 67.90835 | 65.48663 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Jan-87 | 4.710859 | 4.652133 | 4.006316 | 2.068811 | 5.459447 | 2.59723 | 2.068811 | 7.881316 | 4.006316 | 4.975054 |
| Feb-87 | 27.8031 | 22.28784 | 23.45459 | 17.62118 | 20.68367 | 32.89395 | 46.2775 | 33.37107 | 47.37107 | 56.12118 |
| Mar-87 | 14.58032 | 13.0538 | 11.1163 | 7.887144 | 11.27775 | 20.21669 | 27.01985 | 17.57464 | 20.48088 | 33.07452 |
| Apr-87 | 23.48446 | 38.2572 | 21.0697 | 71.38224 | 66.22584 | 17.85946 | 30.8352 | 53.10096 | 43.25712 | 33.41352 |
| May-87 | 67.2819 | 42.15306 | 37.30937 | 38.92385 | 54.90844 | 104.4467 | 104.7988 | 93.17385 | 103.8302 | 116.4238 |
| Jun-87 | 55.55568 | 38.90784 | 54.5328 | 56.40792 | 39.06408 | 56.40792 | 75.62664 | 67.1892 | 89.22048 | 66.25176 |
| Jul-87 | 13.33238 | 17.55964 | 19.49714 | 46.62226 | 43.71595 | 11.74714 | 17.07527 | 28.7003 | 24.3409 | 18.04403 |
| Aug-87 | 58.02134 | 65.94742 | 76.28083 | 89.19742 | 69.82242 | 47.62914 | 45.11938 | 62.55676 | 52.38504 | 53.83807 |
| Sep-87 | 33.79488 | 46.92 | 33.16992 | 41.29488 | 54.42 | 36.0108 | 64.2636 | 74.10744 | 74.10744 | 60.98256 |
| Oct-87 | 17.68027 | 9.754138 | 10.07706 | 9.754138 | 19.44164 | 14.15755 | 14.3557 | 26.70737 | 23.31664 | 12.66038 |
| Nov-87 | 2.853816 | 0.12655 | 4.81404 | 2.00155 | 2.00155 | 2.683368 | 3.642168 | 1.532801 | 2.00155 | 3.407808 |
| Dec-87 | 12.98555 | 7.231754 | 11.10675 | 9.815096 | 12.72133 | 13.16168 | 20.95573 | 19.01823 | 21.4401 | 27.73706 |
| Jan-88 | 0.150617 | 0.150617 | 1.119368 | 0.150617 | 0.150617 | 1.207435 | 0.150617 | 0.150617 | 0.150617 | 0.150617 |
| Feb-88 | 4.846531 | 5.323808 | 5.323808 | 3.573808 | 3.573808 | 6.914723 | 4.667555 | 4.011302 | 3.573808 | 4.448819 |
| Mar-88 | 6.122847 | 6.592534 | 5.300876 | 0.134206 | 2.071705 | 8.236477 | 3.040455 | 2.556086 | 0.134206 | 2.071705 |
| Apr-88 | 7.47348 | 9.518952 | 10.45644 | 7.643952 | 5.300184 | 11.22348 | 11.39395 | 4.83144 | 9.518952 | 20.30018 |
| May-88 | 29.02666 | 36.30695 | 23.71314 | 50.51512 | 43.73406 | 42.76512 | 62.14012 | 31.62446 | 51.48406 | 70.37471 |
| Jun-88 | 17.70214 | 20.14531 | 17.3328 | 37.6452 | 30.61416 | 17.36122 | 22.64532 | 31.08288 | 22.64532 | 31.5516 |
| Jul-88 | 76.58984 | 75.70919 | 76.67788 | 120.2716 | 91.69354 | 90.3283 | 67.7169 | 50.03722 | 44.70919 | 92.17788 |
| Aug-88 | 42.12974 | 45.88744 | 56.8664 | 69.78323 | 45.07995 | 32.97061 | 18.43942 | 34.42389 | 19.40816 | 17.95503 |
| Sep-88 | 52.07616 | 31.96248 | 38.83752 | 41.33736 | 44.61864 | 73.89432 | 101.8061 | 81.64992 | 106.025 | 106.9625 |
| Oct-88 | 0.595289 | 3.296044 | 2.004381 | 7.816886 | 3.941886 | 0.066881 | 2.973123 | 1.035631 | 3.941886 | 2.004381 |
| Nov-88 | 0.037486 | 0.037486 | 0.037486 | 0.037486 | 0.037486 | 0.037486 | 0.037486 | 0.037486 | 0.037486 | 0.037486 |
| Dec-88 | 7.827574 | 8.473416 | 6.858812 | 7.827574 | 10.73381 | 6.594618 | 10.24944 | 14.60881 | 6.858812 | 11.70257 |
| Jan-89 | 5.076039 | 3.373395 | 2.727554 | 4.019237 | 6.925474 | 5.428323 | 12.98017 | 9.347343 | 10.80047 | 15.64424 |
| Feb-89 | 13.95843 | 14.70085 | 10.03419 | 26.36749 | 30.74243 | 16.1857 | 42.33622 | 33.80496 | 41.24243 | 59.18013 |
| Mar-89 | 3.616262 | 5.260179 | 3.322679 | 9.781021 | 8.812283 | 4.849194 | 14.14039 | 6.874783 | 9.781021 | 23.82789 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Apr-89 | 1.818706 | 1.989161 | 0.42666 | 1.989161 | 1.989161 | 2.841432 | 6.442296 | 4.332912 | 3.864168 | 7.614168 |
| May-89 | 23.06727 | 24.06537 | 18.89872 | 15.66956 | 20.99766 | 23.77182 | 33.3493 | 24.87266 | 22.4508 | 35.52898 |
| Jun-89 | 26.75712 | 18.29114 | 17.66614 | 24.5412 | 35.7912 | 31.8708 | 35.32248 | 39.5412 | 43.2912 | 32.50992 |
| Jul-89 | 11.22074 | 21.43665 | 29.18662 | 33.06162 | 18.53041 | 13.15824 | 7.38978 | 12.23352 | 9.811649 | 3.51478 |
| Aug-89 | 63.45898 | 81.4251 | 83.03958 | 104.6751 | 98.37813 | 54.47618 | 25.96411 | 49.45616 | 26.20616 | 22.81563 |
| Sep-89 | 51.51816 | 62.54088 | 48.16584 | 45.0408 | 51.60336 | 50.49528 | 25.82208 | 38.9472 | 20.66585 | 25.82208 |
| Oct-89 | 2.001687 | 4.585024 | 2.324606 | 13.62668 | 10.72044 | 2.706226 | 21.61888 | 9.267314 | 15.56418 | 32.03292 |
| Nov-89 | 0.93095 | 0.078679 | 0.078679 | 0.078679 | 2.891184 | 0.760498 | 11.09431 | 7.578672 | 11.32867 | 14.60993 |
| Dec-89 | 3.080805 | 0.086498 | 3.638582 | 2.023997 | 2.023997 | 3.080805 | 3.477134 | 2.023997 | 3.961502 | 3.961502 |
| Jan-90 | 5.779392 | 2.726363 | 4.663863 | 2.080532 | 3.049284 | 5.603262 | 7.893022 | 5.471153 | 5.955522 | 13.22115 |
| Feb-90 | 10.14973 | 7.710326 | 6.251997 | 8.876986 | 11.93949 | 14.28609 | 21.78324 | 17.62699 | 17.62699 | 29.00195 |
| Mar-90 | 20.24466 | 24.7068 | 14.37346 | 17.60262 | 18.08701 | 23.94353 | 22.68855 | 17.60262 | 19.54012 | 28.7432 |
| Apr-90 | 17.83577 | 13.23348 | 12.92098 | 15.10848 | 16.51474 | 24.14256 | 40.42104 | 25.42104 | 34.79592 | 42.76464 |
| May-90 | 5.231634 | 5.936178 | 3.998678 | 11.74868 | 17.07681 | 7.169134 | 44.68613 | 21.92057 | 46.62375 | 59.70178 |
| Jun-90 | 4.725672 | 1.998401 | 0.748402 | 5.748408 | 5.27964 | 6.430224 | 10.4359 | 9.967152 | 3.873408 | 4.810896 |
| Jul-90 | 82.21944 | 93.13987 | 111.2233 | 162.8899 | 102.3432 | 76.9353 | 80.06184 | 72.31184 | 77.63987 | 115.4212 |
| Aug-90 | 57.15954 | 103.4247 | 97.93495 | 139.5913 | 112.9506 | 44.82997 | 39.5679 | 80.49758 | 47.55995 | 37.87258 |
| Sep-90 | 87.50232 | 95.68416 | 100.9966 | 142.5593 | 131.778 | 83.92272 | 120.528 | 123.3403 | 114.4342 | 146.778 |
| Oct-90 | 31.10565 | 44.02248 | 43.05379 | 54.35565 | 44.66827 | 26.17392 | 46.3636 | 41.76196 | 45.63696 | 58.23065 |
| Nov-90 | 18.51492 | 16.98082 | 15.41832 | 9.480816 | 15.10582 | 20.38992 | 24.94968 | 24.48072 | 26.35584 | 25.4184 |
| Dec-90 | 8.518378 | 10.39718 | 8.136756 | 19.43884 | 14.5951 | 11.51271 | 10.7201 | 12.6576 | 9.751335 | 6.845098 |
| Jan-91 | 33.04947 | 25.29947 | 26.9142 | 17.5495 | 20.45573 | 32.87339 | 42.2525 | 29.65882 | 38.8621 | 56.29947 |
| Feb-91 | 4.728237 | 5.947939 | 8.28128 | 7.114598 | 4.927104 | 4.887344 | 4.927104 | 4.927104 | 6.23961 | 4.48961 |
| Mar-91 | 3.352538 | 4.057082 | 3.088319 | 5.994582 | 5.025819 | 2.471843 | 3.088319 | 5.994582 | 4.057082 | 3.088319 |
| Apr-91 | 12.06427 | 17.00746 | 11.69494 | 11.38246 | 20.75746 | 4.3938 | 24.03864 | 32.94504 | 33.88248 | 25.91376 |
| May-91 | 24.81711 | 26.63718 | 29.2206 | 23.40805 | 28.25191 | 17.77168 | 28.73626 | 25.82994 | 28.25191 | 39.87691 |
| Jun-91 | 26.88888 | 22.00258 | 19.19009 | 37.62768 | 47.47128 | 27.40032 | 55.90872 | 58.72128 | 51.69 | 69.50256 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Jul-91 | 104.0154 | 118.9282 | 116.0221 | 201.595 | 156.0637 | 112.8221 | 72.7513 | 89.21998 | 79.53236 | 70.32933 |
| Aug-91 | 46.04988 | 47.22416 | 53.68258 | 56.26574 | 54.81271 | 49.7488 | 72.49238 | 75.64074 | 70.79706 | 60.62509 |
| Sep-91 | 123.81 | 119.4348 | 120.06 | 97.56 | 98.96616 | 122.6167 | 121.7006 | 97.56 | 113.4974 | 130.3723 |
| Oct-91 | 2.342752 | 1.990478 | 2.636314 | 1.990478 | 1.021728 | 3.927973 | 8.287342 | 3.443604 | 4.896735 | 9.740473 |
| Nov-91 | 14.91115 | 16.9566 | 15.0816 | 16.9566 | 14.14411 | 18.14978 | 17.42534 | 14.61286 | 16.01911 | 17.42534 |
| Dec-91 | 65.84152 | 53.10102 | 59.23629 | 56.33022 | 53.90826 | 70.77325 | 70.61924 | 56.81457 | 66.0176 | 86.36129 |
| Jan-92 | 34.81746 | 42.74354 | 46.94144 | 42.74354 | 35.96223 | 30.2379 | 39.59494 | 35.47789 | 34.02486 | 51.94658 |
| Feb-92 | 33.3695 | 36.28621 | 22.8695 | 29.8695 | 38.61962 | 36.23312 | 57.8695 | 48.68214 | 52.61962 | 65.74467 |
| Mar-92 | 7.50515 | 2.690775 | 3.659513 | 3.982434 | 6.888671 | 9.971063 | 21.66213 | 22.87306 | 23.35743 | 27.71673 |
| Apr-92 | 11.37792 | 6.377928 | 7.002912 | 9.50292 | 11.37792 | 13.93474 | 34.81536 | 29.19048 | 37.62792 | 40.44048 |
| May-92 | 157.4257 | 125.4277 | 85.70905 | 108.6359 | 125.5892 | 192.6531 | 149.5656 | 145.9329 | 133.8235 | 138.6672 |
| Jun-92 | 57.65856 | 28.96536 | 33.34032 | 30.21528 | 40.99656 | 56.63592 | 56.46528 | 62.55912 | 63.02784 | 65.8404 |
| Jul-92 | 36.39846 | 42.73933 | 40.47881 | 69.86433 | 53.39564 | 40.62562 | 69.86433 | 54.36433 | 55.33302 | 70.83302 |
| Aug-92 | 30.71257 | 38.16918 | 28.80446 | 67.87735 | 70.29932 | 34.41149 | 53.10399 | 83.37735 | 55.28366 | 40.26801 |
| Sep-92 | 22.54265 | 47.54256 | 28.1676 | 45.04272 | 45.04272 | 17.94038 | 15.98016 | 29.10504 | 15.04265 | 10.35516 |
| Oct-92 | 2.225324 | 1.403353 | 5.924174 | 2.049187 | 2.049187 | 0.992367 | 4.471068 | 5.924174 | 5.924174 | 3.986674 |
| Nov-92 | 15.26215 | 23.21671 | 16.3417 | 22.5917 | 21.65422 | 18.50081 | 8.294832 | 16.02922 | 8.529216 | 8.99796 |
| Dec-92 | 12.60775 | 12.37292 | 8.820814 | 17.53958 | 16.57081 | 14.36912 | 14.39114 | 20.44581 | 14.63331 | 14.14895 |
| Jan-93 | 24.20686 | 24.61784 | 25.58666 | 25.26376 | 21.87305 | 26.32049 | 18.96679 | 22.84179 | 17.51366 | 21.38866 |
| Feb-93 | 8.516973 | 5.918483 | 5.335142 | 5.335142 | 4.022659 | 14.88061 | 12.33514 | 7.522659 | 10.58514 | 14.96015 |
| Mar-93 | 4.551792 | 5.315037 | 3.377537 | 7.898378 | 8.867141 | 8.250662 | 8.382747 | 6.929641 | 5.960878 | 11.28901 |
| Apr-93 | 8.700552 | 7.67784 | 5.490336 | 13.30284 | 10.49033 | 17.39374 | 21.0372 | 6.271584 | 13.30284 | 29.70912 |
| May-93 | 20.04346 | 16.9317 | 10.79628 | 23.39005 | 28.71815 | 29.37858 | 44.7025 | 37.92118 | 34.04618 | 46.15578 |
| Jun-93 | 11.07732 | 26.41824 | 20.79324 | 63.91824 | 32.04312 | 11.41824 | 33.91824 | 19.38698 | 38.60568 | 40.01208 |
| Jul-93 | 73.38791 | 98.28166 | 94.40666 | 145.4277 | 118.787 | 65.99007 | 35.95876 | 70.83376 | 33.0527 | 41.28704 |
| Aug-93 | 35.50591 | 48.54005 | 38.52953 | 60.16505 | 52.89939 | 46.25026 | 58.22742 | 32.5557 | 45.63374 | 69.36808 |
| Sep-93 | 16.56881 | 15.0347 | 12.22222 | 15.0347 | 19.25345 | 23.04607 | 45.97224 | 28.15968 | 32.84712 | 55.81608 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Oct-93 | 14.53054 | 16.87903 | 17.52487 | 13.64987 | 11.71237 | 16.6442 | 7.83737 | 8.321739 | 5.89987 | 9.290502 |
| Nov-93 | 1.804654 | 0.100109 | 1.66261 | 0.100109 | 0.100109 | 2.486472 | 2.912616 | 1.975109 | 3.850104 | 1.975109 |
| Dec-93 | 6.29119 | 16.27225 | 10.13683 | 33.06386 | 24.82951 | 5.410517 | 18.0483 | 18.53267 | 20.47017 | 20.47017 |
| Jan-94 | 10.15615 | 8.512203 | 4.314282 | 9.803862 | 11.25699 | 12.26978 | 48.55394 | 37.41328 | 54.36631 | 56.30394 |
| Feb-94 | 2.194877 | 2.460035 | 1.876697 | 5.376694 | 3.626694 | 3.149418 | 4.501706 | 2.314189 | 1.876697 | 2.751706 |
| Mar-94 | 5.795041 | 15.65867 | 12.10659 | 17.59617 | 16.14306 | 1.215495 | 9.84617 | 8.393064 | 9.84617 | 11.2993 |
| Apr-94 | 9.340008 | 5.760456 | 5.135472 | 7.635456 | 8.1042 | 9.340008 | 19.3542 | 16.54171 | 18.88546 | 26.38536 |
| May-94 | 63.4513 | 80.94745 | 64.80166 | 77.71824 | 57.8589 | 75.95694 | 50.59324 | 45.74955 | 45.74955 | 58.34324 |
| Jun-94 | 12.4135 | 13.89077 | 18.26578 | 24.51576 | 10.92204 | 10.70897 | 9.750144 | 6.234528 | 6.703272 | 12.79704 |
| Jul-94 | 30.24782 | 23.37854 | 21.44104 | 33.06609 | 29.19109 | 49.09433 | 40.33174 | 38.87846 | 33.06609 | 48.08174 |
| Aug-94 | 24.52564 | 17.48018 | 12.63644 | 23.29268 | 23.77705 | 25.23028 | 12.63644 | 17.48018 | 9.730181 | 10.21455 |
| Sep-94 | 45.57528 | 48.18888 | 34.75128 | 46.93896 | 60.53256 | 44.2116 | 40.84512 | 64.75128 | 48.81384 | 38.97024 |
| Oct-94 | 14.00057 | 15.58578 | 22.68997 | 23.33578 | 18.49205 | 12.94374 | 26.48417 | 19.94518 | 19.46078 | 32.0545 |
| Nov-94 | 7.585776 | 4.460784 | 8.523288 | 3.835776 | 1.492034 | 13.21078 | 23.2889 | 7.117032 | 16.96078 | 37.58568 |
| Dec-94 | 8.898463 | 16.23748 | 17.52914 | 17.52914 | 10.7479 | 6.080266 | 17.77133 | 7.357267 | 8.810398 | 30.12282 |
| Jan-95 | 9.592814 | 6.539785 | 8.154364 | 3.956443 | 3.472074 | 12.76327 | 8.800206 | 8.315837 | 5.893943 | 7.831443 |
| Feb-95 | 10.5999 | 10.01656 | 11.47489 | 8.849904 | 5.787398 | 13.78171 | 13.44365 | 6.224893 | 9.724893 | 20.66239 |
| Mar-95 | 3.114161 | 5.286517 | 7.224017 | 5.932358 | 3.026096 | 3.114161 | 17.31516 | 2.057348 | 11.74486 | 35.47913 |
| Apr-95 | 13.79083 | 23.27947 | 15.46697 | 26.40456 | 29.21688 | 10.8931 | 40.9356 | 31.092 | 39.52944 | 53.12328 |
| May-95 | 54.71475 | 30.4668 | 24.65423 | 25.29997 | 32.08128 | 75.8513 | 101.5892 | 66.47194 | 82.45628 | 124.1126 |
| Jun-95 | 48.18576 | 41.3676 | 40.42992 | 61.99248 | 58.7112 | 47.67432 | 32.92992 | 52.14864 | 42.30504 | 27.77376 |
| Jul-95 | 6.291537 | 7.876778 | 11.42886 | 21.43928 | 10.78302 | 9.461994 | 16.35334 | 7.392409 | 11.75178 | 20.95491 |
| Aug-95 | 12.39898 | 20.7361 | 26.54865 | 40.75682 | 20.89757 | 20.32511 | 18.23351 | 10.72568 | 10.72568 | 25.25682 |
| Sep-95 | 81.73824 | 103.2156 | 101.3407 | 99.4656 | 86.34072 | 91.9656 | 59.15304 | 55.87176 | 65.7156 | 68.99688 |
| Oct-95 | 9.385014 | 11.6748 | 11.35188 | 17.4873 | 17.97167 | 7.623669 | 15.06543 | 10.70604 | 10.70604 | 29.11222 |
| Nov-95 | 0.127949 | 3.25296 | 1.377948 | 7.627944 | 5.2842 | 0.127949 | 25.206 | 5.2842 | 24.50304 | 40.9092 |
| Dec-95 | 15.56193 | 16.20774 | 13.94732 | 13.62443 | 13.62443 | 12.5676 | 8.780663 | 13.14003 | 7.811926 | 7.327532 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Jan-96 | 2.929054 | 4.631698 | 4.308777 | 5.923356 | 3.017118 | 2.752899 | 0.110861 | 0.595237 | 0.110861 | 0.110861 |
| Feb-96 | 1.585938 | 1.320785 | 1.320785 | 3.654112 | 3.654112 | 0.631391 | 2.779123 | 3.654112 | 2.779123 | 4.091629 |
| Mar-96 | 1.411871 | 0.824749 | 0.178917 | 2.116417 | 0.178917 | 1.94028 | 1.147667 | 0.178917 | 1.147667 | 3.08517 |
| Apr-96 | 17.35344 | 12.63754 | 18.88752 | 9.51252 | 9.043776 | 17.86481 | 23.80942 | 19.35629 | 26.38752 | 24.98136 |
| May-96 | 5.589226 | 1.420675 | 0.129008 | 2.066507 | 6.425878 | 8.407423 | 26.52757 | 20.95714 | 31.12896 | 34.51962 |
| Jun-96 | 49.21488 | 36.37416 | 60.12408 | 54.49896 | 39.96768 | 70.69224 | 42.78024 | 33.40536 | 27.31152 | 34.81152 |
| Jul-96 | 39.90593 | 46.5992 | 61.7763 | 58.2242 | 43.69289 | 33.91747 | 21.1695 | 20.44294 | 19.4742 | 27.2242 |
| Aug-96 | 76.51172 | 55.61028 | 72.72476 | 89.1937 | 68.84976 | 98.00042 | 107.1154 | 83.38107 | 97.91238 | 110.0217 |
| Sep-96 | 44.34888 | 67.53072 | 51.90576 | 108.7807 | 103.6246 | 31.5648 | 101.2807 | 107.3746 | 120.0307 | 109.2494 |
| Oct-96 | 1.304554 | 2.009098 | 13.95702 | 5.884098 | 2.009098 | 2.009098 | 11.93879 | 2.97786 | 8.79036 | 23.80597 |
| Nov-96 | 17.29358 | 16.32766 | 13.82767 | 16.95266 | 16.01518 | 23.77085 | 62.18712 | 35.23392 | 50.70264 | 70.39008 |
| Dec-96 | 0.178007 | 0.823841 | 2.438425 | 4.053014 | 0.178007 | 0.178007 | 0.90457 | 0.178007 | 0.178007 | 1.631133 |
| Jan-97 | 5.955422 | 7.892922 | 9.507502 | 9.830422 | 6.92416 | 4.898595 | 6.92416 | 3.04916 | 4.98666 | 12.25229 |
| Feb-97 | 20.61837 | 26.92906 | 22.84576 | 24.59565 | 26.78323 | 22.84576 | 32.03312 | 27.65818 | 30.7207 | 47.34576 |
| Mar-97 | 2.959384 | 3.37037 | 4.339132 | 4.016211 | 11.76621 | 1.374163 | 24.35995 | 15.15684 | 14.67245 | 38.89111 |
| Apr-97 | 38.304 | 35.74728 | 44.80968 | 35.74728 | 31.52856 | 41.7132 | 52.15344 | 54.49728 | 54.49728 | 58.716 |
| May-97 | 33.92144 | 43.37421 | 34.33238 | 58.22842 | 46.11907 | 53.64885 | 43.21276 | 37.40014 | 45.63448 | 48.54079 |
| Jun-97 | 34.06968 | 21.39934 | 31.39944 | 47.0244 | 49.368 | 55.88808 | 70.22736 | 47.0244 | 51.71184 | 71.868 |
| Jul-97 | 31.6763 | 38.25202 | 41.15833 | 75.71018 | 47.13215 | 38.19324 | 14.43685 | 17.58528 | 11.77278 | 12.74155 |
| Aug-97 | 39.87245 | 47.21151 | 35.26337 | 67.8781 | 56.2531 | 44.27569 | 40.5108 | 45.11244 | 47.53441 | 37.84678 |
| Sep-97 | 43.55616 | 38.2152 | 33.21504 | 37.59024 | 31.96512 | 54.97656 | 36.88704 | 33.37128 | 41.34024 | 32.90256 |
| Oct-97 | 22.98407 | 10.41967 | 21.07593 | 11.71135 | 9.773854 | 32.67152 | 15.82853 | 5.41446 | 10.74259 | 19.94572 |
| Nov-97 | 9.826728 | 11.36081 | 10.11082 | 13.23581 | 13.70458 | 11.53128 | 18.86081 | 15.57958 | 16.98581 | 21.20458 |
| Dec-97 | 30.4425 | 29.85548 | 28.56365 | 33.08469 | 24.8501 | 33.96534 | 33.56903 | 33.56903 | 31.14706 | 34.05338 |
| Jan-98 | 0.489701 | 0.783261 | 2.074929 | 4.012417 | 0.137429 | 2.427201 | 8.613982 | 1.106179 | 4.981179 | 11.76242 |
| Feb-98 | 4.131725 | 3.071107 | 4.821107 | 3.654448 | 2.779437 | 6.677171 | 10.21695 | 6.716954 | 9.779437 | 11.52944 |
| Mar-98 | 9.089101 | 2.689486 | 2.043659 | 3.981169 | 4.949906 | 15.25388 | 24.08271 | 10.27804 | 12.69991 | 37.88746 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Apr-98 | 0.204811 | 0.204811 | 0.204811 | 0.204811 | 0.204811 | 0.716174 | 0.439186 | 0.204811 | 0.204811 | 0.204811 |
| May-98 | 4.922254 | 9.20824 | 8.239502 | 11.79158 | 8.885319 | 6.859754 | 10.09628 | 8.40095 | 5.979082 | 20.51032 |
| Jun-98 | 6.964128 | 5.770944 | 5.770944 | 11.39594 | 10.9272 | 7.98684 | 24.28656 | 17.02094 | 26.39592 | 28.73976 |
| Jul-98 | 19.04722 | 33.78405 | 33.78405 | 64.13826 | 37.4976 | 20.45633 | 8.677198 | 13.27876 | 8.919394 | 8.919394 |
| Aug-98 | 56.34312 | 61.50995 | 58.28074 | 58.28074 | 60.21812 | 50.35466 | 96.06206 | 62.15574 | 73.78074 | 123.1871 |
| Sep-98 | 12.02885 | 16.34702 | 12.59702 | 15.09703 | 15.09703 | 14.58566 | 12.05016 | 16.03454 | 9.472032 | 9.472032 |
| Oct-98 | 57.68902 | 53.69671 | 60.80092 | 64.03013 | 56.28013 | 61.03578 | 41.26447 | 48.53013 | 44.65513 | 38.8425 |
| Nov-98 | 8.777064 | 9.458904 | 6.333888 | 9.458904 | 11.3339 | 9.458904 | 40.39632 | 22.11514 | 43.20888 | 53.99016 |
| Dec-98 | 14.39196 | 15.62489 | 15.94781 | 11.74989 | 9.328024 | 16.15331 | 14.89835 | 11.74989 | 13.68739 | 15.62489 |
| Jan-99 | 5.219408 | 7.215634 | 5.601055 | 3.986451 | 2.048961 | 4.690994 | 5.19741 | 3.502082 | 4.955214 | 5.439582 |
| Feb-99 | 0.106196 | 0.106196 | 0.106196 | 0.106196 | 0.106196 | 0.106196 | 1.637447 | 0.106196 | 0.981196 | 2.293693 |
| Mar-99 | 11.058 | 13.0542 | 6.595882 | 25.32502 | 23.87191 | 22.683 | 42.27805 | 24.35628 | 32.10633 | 52.45002 |
| Apr-99 | 16.18303 | 6.410304 | 7.035312 | 3.91032 | 0.629062 | 22.83077 | 17.26968 | 7.191552 | 17.97281 | 27.81648 |
| May-99 | 42.38469 | 18.84103 | 14.96603 | 9.799348 | 12.70561 | 53.30512 | 33.53382 | 41.28382 | 49.51816 | 34.5025 |
| Jun-99 | 35.80488 | 40.80504 | 42.67992 | 62.05488 | 35.33616 | 43.81632 | 73.7736 | 55.0236 | 63.93 | 76.58616 |
| Jul-99 | 27.2986 | 77.02781 | 70.89229 | 159.0486 | 81.5486 | 27.47468 | 15.18918 | 10.82979 | 11.79855 | 23.42355 |
| Aug-99 | 7.833179 | 22.0415 | 24.94781 | 52.3957 | 26.23939 | 23.33318 | 8.317548 | 5.895679 | 6.864417 | 11.22379 |
| Sep-99 | 20.89423 | 12.59878 | 11.66129 | 20.72378 | 24.94248 | 22.59878 | 12.52066 | 32.44248 | 17.91127 | 5.723784 |
| Oct-99 | 2.71813 | 5.888586 | 4.596928 | 7.826086 | 2.497955 | 2.542 | 10.97452 | 2.982349 | 4.919849 | 19.45109 |
| Nov-99 | 0.06815 | 0.06815 | 0.06815 | 0.06815 | 0.06815 | 0.06815 | 0.06815 | 0.06815 | 0.06815 | 0.06815 |
| Dec-99 | 2.245608 | 5.944461 | 4.975723 | 7.881961 | 3.522592 | 2.245608 | 2.553854 | 3.038223 | 5.944461 | 2.069471 |
| Jan-00 | 8.05566 | 2.067018 | 0.452434 | 0.129518 | 2.551399 | 12.45907 | 9.332637 | 10.78577 | 6.910768 | 4.973268 |
| Feb-00 | 5.23553 | 7.144614 | 4.227955 | 5.394614 | 6.70712 | 2.690061 | 5.175856 | 9.769603 | 6.269603 | 4.95712 |
| Mar-00 | 6.838848 | 0.791499 | 0.468584 | 2.083168 | 3.051913 | 27.0945 | 20.73161 | 13.22378 | 10.80191 | 17.09878 |
| Apr-00 | 3.561672 | 8.277576 | 7.965072 | 7.652592 | 5.777592 | 4.925304 | 6.949464 | 7.183824 | 5.777592 | 9.996336 |
| May-00 | 2.253648 | 1.431679 | 0.462929 | 4.015021 | 2.077513 | 9.475237 | 13.21813 | 0.624387 | 1.108763 | 20.96813 |
| Jun-00 | 66.774 | 95.1264 | 86.68896 | 138.8762 | 94.3452 | 76.66032 | 97.392 | 84.97008 | 61.06392 | 120.1262 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Jul-00 | 12.82477 | 5.309606 | 30.17416 | 15.64295 | 10.79921 | 13.35316 | 5.955447 | 7.892947 | 7.892947 | 5.471078 |
| Aug-00 | 10.51314 | 21.4336 | 27.24602 | 33.05865 | 24.8243 | 3.467685 | 1.332023 | 2.542967 | 2.058586 | 0.121086 |
| Sep-00 | 0.086978 | 0.086978 | 0.086978 | 1.961978 | 1.961978 | 0.086978 | 8.758848 | 0.086978 | 1.961978 | 14.61823 |
| Oct-00 | 50.61854 | 45.92166 | 42.04666 | 77.56746 | 90.64549 | 60.65832 | 96.94246 | 90.16114 | 94.03614 | 112.9268 |
| Nov-00 | 19.33915 | 10.70278 | 11.64029 | 11.32778 | 13.20278 | 30.93 | 36.1716 | 23.51527 | 32.89032 | 45.07776 |
| Dec-00 | 3.41563 | 6.527385 | 8.141964 | 5.881543 | 2.490937 | 10.9895 | 7.334674 | 1.037801 | 4.912806 | 8.303437 |

# Appendix F: NARR Monthly Temperature Data

NARR Monthly temperature data in Celsius Degrees

| Date | Watershed | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 13070001 | 13070003 | 13070004 | 13070005 | 13070006 | 13070007 | 13070008 | 13070009 | 13070010 | 13070011 |
| Jan-81 | 8.687 | 8.810 | 8.613 | 8.263 | 8.253 | 7.746 | 9.557 | 9.163 | 9.270 | 9.450 |
| Feb-81 | 12.869 | 13.120 | 12.728 | 12.450 | 12.450 | 11.940 | 13.501 | 13.293 | 13.160 | 13.290 |
| Mar-81 | 16.207 | 15.840 | 15.720 | 15.130 | 14.693 | 15.841 | 16.503 | 15.633 | 15.725 | 16.243 |
| Apr-81 | 24.006 | 23.520 | 23.520 | 22.773 | 22.193 | 23.035 | 24.008 | 23.387 | 23.120 | 23.638 |
| May-81 | 28.368 | 27.473 | 28.023 | 27.137 | 25.710 | 27.150 | 27.810 | 27.423 | 26.720 | 26.680 |
| Jun-81 | 33.904 | 33.557 | 34.038 | 32.633 | 31.160 | 32.258 | 31.022 | 31.633 | 30.630 | 29.643 |
| Jul-81 | 34.770 | 34.253 | 34.490 | 33.333 | 31.793 | 34.006 | 34.236 | 33.583 | 33.270 | 33.133 |
| Aug-81 | 32.763 | 31.647 | 32.442 | 30.740 | 29.303 | 32.089 | 33.050 | 31.940 | 31.920 | 32.193 |
| Sep-81 | 28.754 | 27.677 | 28.220 | 26.963 | 26.053 | 28.187 | 29.741 | 28.587 | 28.835 | 29.090 |
| Oct-81 | 21.699 | 21.273 | 21.338 | 20.367 | 19.963 | 21.158 | 22.176 | 21.263 | 21.365 | 21.558 |
| Nov-81 | 15.292 | 15.243 | 15.217 | 14.403 | 14.360 | 14.510 | 15.708 | 15.697 | 15.625 | 15.373 |
| Dec-81 | 10.296 | 10.590 | 10.453 | 9.897 | 9.923 | 9.581 | 10.547 | 10.757 | 10.630 | 10.513 |
| Jan-82 | 8.439 | 9.527 | 8.863 | 8.780 | 9.233 | 7.171 | 9.119 | 9.827 | 9.645 | 8.943 |
| Feb-82 | 11.339 | 12.433 | 11.743 | 12.097 | 12.100 | 10.248 | 11.849 | 12.433 | 12.080 | 11.115 |
| Mar-82 | 18.720 | 19.077 | 18.585 | 18.237 | 18.250 | 17.793 | 19.532 | 19.047 | 19.180 | 19.245 |
| Apr-82 | 23.425 | 23.560 | 23.165 | 22.700 | 22.523 | 22.172 | 23.958 | 23.617 | 23.555 | 23.583 |
| May-82 | 28.016 | 27.357 | 27.687 | 26.693 | 25.550 | 26.867 | 28.394 | 27.697 | 27.450 | 27.720 |
| Jun-82 | 34.262 | 33.627 | 33.760 | 32.810 | 31.580 | 33.097 | 33.902 | 33.600 | 33.275 | 32.545 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Jul-82 | 35.500 | 34.850 | 34.993 | 33.850 | 32.230 | 34.536 | 34.962 | 34.380 | 34.100 | 33.853 |
| Aug-82 | 35.073 | 34.007 | 34.595 | 33.153 | 31.743 | 34.351 | 34.874 | 34.080 | 33.815 | 33.842 |
| Sep-82 | 30.892 | 30.323 | 30.373 | 29.347 | 28.420 | 30.182 | 31.129 | 30.593 | 30.240 | 30.645 |
| Oct-82 | 22.206 | 22.433 | 21.858 | 21.617 | 21.403 | 21.403 | 23.234 | 22.757 | 22.690 | 22.840 |
| Nov-82 | 13.516 | 14.107 | 13.385 | 13.380 | 13.357 | 12.368 | 14.778 | 14.557 | 14.470 | 14.800 |
| Dec-82 | 7.834 | 8.197 | 7.508 | 7.713 | 7.523 | 7.008 | 9.472 | 8.967 | 9.175 | 9.610 |
| Jan-83 | 7.618 | 8.817 | 8.138 | 8.150 | 8.333 | 5.795 | 8.912 | 9.163 | 9.120 | 8.828 |
| Feb-83 | 12.709 | 12.817 | 12.578 | 12.087 | 11.790 | 11.754 | 13.229 | 13.080 | 12.885 | 12.803 |
| Mar-83 | 17.512 | 17.330 | 17.148 | 16.490 | 15.997 | 16.813 | 18.034 | 17.657 | 17.380 | 17.685 |
| Apr-83 | 18.813 | 20.233 | 19.062 | 19.490 | 19.220 | 18.130 | 21.326 | 20.983 | 20.940 | 21.288 |
| May-83 | 27.992 | 27.877 | 27.943 | 27.230 | 26.290 | 26.651 | 29.007 | 28.453 | 28.290 | 28.870 |
| Jun-83 | 33.324 | 33.187 | 33.200 | 32.167 | 31.243 | 31.971 | 32.739 | 33.017 | 32.200 | 31.353 |
| Jul-83 | 35.995 | 35.520 | 35.907 | 34.530 | 33.150 | 34.791 | 34.752 | 34.940 | 34.230 | 33.308 |
| Aug-83 | 35.418 | 34.533 | 35.185 | 33.630 | 32.130 | 34.810 | 35.146 | 34.517 | 34.185 | 33.923 |
| Sep-83 | 31.245 | 30.883 | 31.385 | 29.877 | 28.897 | 30.253 | 30.612 | 30.607 | 29.845 | 29.845 |
| Oct-83 | 23.523 | 22.717 | 22.967 | 22.143 | 21.383 | 22.887 | 23.852 | 23.273 | 23.110 | 23.018 |
| Nov-83 | 15.183 | 15.120 | 15.105 | 14.373 | 14.097 | 14.310 | 15.834 | 15.370 | 15.540 | 15.548 |
| Dec-83 | 4.036 | 6.283 | 5.648 | 5.773 | 6.683 | 2.014 | 4.842 | 5.987 | 6.000 | 4.648 |
| Jan-84 | 4.942 | 7.163 | 5.988 | 6.693 | 7.267 | 3.942 | 6.868 | 7.133 | 7.285 | 6.565 |
| Feb-84 | 11.113 | 11.537 | 11.067 | 10.777 | 10.610 | 10.382 | 12.217 | 12.030 | 12.090 | 11.965 |
| Mar-84 | 16.977 | 18.170 | 17.423 | 17.343 | 17.227 | 16.537 | 18.563 | 18.190 | 18.390 | 18.260 |
| Apr-84 | 22.373 | 22.607 | 22.252 | 21.760 | 21.490 | 21.074 | 23.109 | 22.963 | 23.030 | 22.937 |
| May-84 | 28.693 | 28.970 | 29.118 | 28.217 | 27.267 | 27.216 | 28.981 | 28.650 | 28.440 | 28.563 |
| Jun-84 | 32.628 | 31.853 | 32.645 | 31.037 | 29.607 | 31.361 | 33.214 | 32.240 | 32.240 | 32.863 |
| Jul-84 | 34.429 | 33.430 | 34.173 | 32.567 | 30.567 | 33.143 | 34.121 | 33.727 | 33.515 | 33.393 |
| Aug-84 | 33.377 | 32.070 | 32.823 | 31.483 | 29.833 | 32.366 | 33.993 | 33.207 | 33.050 | 33.270 |
| Sep-84 | 27.293 | 26.713 | 27.115 | 25.977 | 24.840 | 26.497 | 28.191 | 27.043 | 26.895 | 27.925 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Oct-84 | 20.468 | 19.590 | 19.815 | 19.183 | 18.263 | 19.930 | 21.947 | 20.533 | 21.080 | 21.635 |
| Nov-84 | 13.119 | 12.910 | 12.780 | 12.340 | 12.183 | 12.396 | 14.033 | 13.483 | 13.560 | 13.825 |
| Dec-84 | 11.425 | 11.483 | 11.003 | 11.143 | 11.100 | 10.512 | 13.201 | 12.477 | 13.015 | 13.340 |
| Jan-85 | 5.623 | 5.850 | 5.920 | 5.613 | 5.347 | 4.266 | 6.448 | 6.537 | 6.545 | 6.130 |
| Feb-85 | 9.629 | 10.527 | 10.118 | 10.177 | 10.080 | 8.306 | 11.010 | 11.067 | 11.050 | 10.335 |
| Mar-85 | 18.349 | 18.363 | 18.130 | 17.660 | 17.333 | 17.632 | 19.080 | 18.267 | 18.325 | 18.823 |
| Apr-85 | 24.666 | 24.430 | 24.325 | 23.603 | 22.997 | 23.419 | 24.493 | 24.310 | 24.040 | 23.915 |
| May-85 | 30.212 | 29.727 | 29.990 | 29.233 | 28.070 | 28.696 | 30.283 | 30.267 | 30.000 | 29.303 |
| Jun-85 | 32.888 | 32.873 | 33.343 | 31.907 | 30.540 | 31.216 | 31.627 | 31.567 | 31.030 | 30.168 |
| Jul-85 | 34.232 | 33.317 | 34.025 | 32.397 | 30.777 | 32.964 | 33.284 | 32.990 | 32.705 | 32.002 |
| Aug-85 | 35.142 | 33.967 | 35.035 | 32.983 | 31.410 | 34.072 | 34.564 | 33.573 | 33.395 | 33.722 |
| Sep-85 | 29.260 | 28.427 | 29.035 | 27.430 | 26.087 | 28.381 | 29.500 | 28.653 | 28.820 | 28.870 |
| Oct-85 | 21.516 | 21.040 | 20.845 | 20.433 | 19.927 | 20.713 | 22.849 | 21.843 | 22.415 | 22.293 |
| Nov-85 | 15.512 | 15.357 | 14.967 | 14.700 | 14.677 | 14.720 | 17.554 | 16.610 | 17.225 | 17.505 |
| Dec-85 | 7.560 | 8.217 | 7.883 | 7.630 | 8.010 | 6.427 | 8.292 | 8.547 | 8.820 | 8.318 |
| Jan-86 | 9.258 | 10.133 | 9.788 | 9.280 | 9.460 | 8.007 | 9.910 | 10.223 | 10.135 | 9.515 |
| Feb-86 | 13.293 | 14.770 | 14.013 | 13.983 | 14.147 | 11.815 | 14.760 | 15.017 | 15.170 | 14.835 |
| Mar-86 | 18.687 | 18.843 | 18.703 | 17.847 | 17.463 | 18.067 | 19.113 | 18.747 | 18.745 | 19.010 |
| Apr-86 | 26.326 | 26.417 | 26.083 | 25.557 | 25.180 | 24.805 | 26.884 | 26.517 | 26.530 | 26.825 |
| May-86 | 28.633 | 28.623 | 28.578 | 27.930 | 27.247 | 27.217 | 28.976 | 28.693 | 28.690 | 28.568 |
| Jun-86 | 32.472 | 31.927 | 32.470 | 31.007 | 29.443 | 30.832 | 31.520 | 31.530 | 31.410 | 30.563 |
| Jul-86 | 34.657 | 33.570 | 33.980 | 32.750 | 31.623 | 33.177 | 34.200 | 34.110 | 33.940 | 33.328 |
| Aug-86 | 33.088 | 32.207 | 33.173 | 31.170 | 30.007 | 31.737 | 32.744 | 31.850 | 32.345 | 31.948 |
| Sep-86 | 28.704 | 27.563 | 28.155 | 26.840 | 25.750 | 27.865 | 29.449 | 28.343 | 29.075 | 29.180 |
| Oct-86 | 20.524 | 20.063 | 20.180 | 19.323 | 18.897 | 19.815 | 20.767 | 20.047 | 20.405 | 19.975 |
| Nov-86 | 13.226 | 13.180 | 12.815 | 12.557 | 12.643 | 12.306 | 14.222 | 13.767 | 13.925 | 13.863 |
| Dec-86 | 8.293 | 8.487 | 8.110 | 7.983 | 7.870 | 7.378 | 9.412 | 8.830 | 9.065 | 9.198 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Jan-87 | 6.753 | 7.663 | 7.053 | 7.043 | 7.297 | 5.837 | 8.501 | 8.183 | 8.540 | 8.300 |
| Feb-87 | 11.491 | 11.630 | 11.140 | 10.930 | 10.893 | 10.674 | 12.527 | 11.870 | 12.045 | 12.175 |
| Mar-87 | 14.287 | 14.550 | 14.328 | 13.670 | 13.590 | 13.553 | 14.601 | 14.180 | 14.280 | 14.328 |
| Apr-87 | 21.143 | 20.657 | 20.970 | 19.837 | 19.170 | 20.090 | 20.941 | 20.317 | 20.350 | 20.528 |
| May-87 | 27.879 | 27.053 | 27.740 | 26.340 | 24.817 | 26.651 | 27.850 | 27.073 | 26.820 | 27.063 |
| Jun-87 | 31.830 | 31.737 | 32.145 | 30.580 | 29.333 | 30.423 | 30.207 | 29.983 | 29.360 | 29.180 |
| Jul-87 | 34.318 | 33.777 | 34.460 | 32.560 | 30.793 | 32.868 | 32.954 | 32.600 | 32.075 | 31.743 |
| Aug-87 | 33.925 | 33.020 | 33.798 | 32.043 | 30.317 | 32.979 | 34.018 | 32.770 | 32.655 | 32.855 |
| Sep-87 | 29.170 | 28.267 | 28.573 | 27.420 | 26.230 | 28.419 | 29.094 | 28.270 | 28.045 | 28.573 |
| Oct-87 | 23.057 | 22.823 | 22.978 | 21.907 | 21.423 | 22.444 | 23.088 | 22.503 | 22.270 | 22.585 |
| Nov-87 | 13.997 | 13.897 | 13.735 | 13.157 | 12.953 | 13.197 | 14.812 | 14.323 | 14.360 | 14.678 |
| Dec-87 | 7.986 | 8.720 | 8.180 | 8.183 | 8.367 | 7.490 | 9.583 | 9.150 | 9.510 | 9.913 |
| Jan-88 | 7.265 | 7.843 | 7.338 | 7.190 | 7.590 | 6.349 | 7.686 | 7.860 | 7.695 | 7.580 |
| Feb-88 | 11.741 | 12.380 | 11.500 | 11.753 | 12.113 | 10.749 | 12.756 | 12.730 | 12.865 | 12.562 |
| Mar-88 | 16.747 | 17.093 | 16.692 | 16.227 | 16.243 | 15.948 | 17.366 | 16.893 | 16.955 | 17.472 |
| Apr-88 | 23.375 | 23.290 | 23.038 | 22.410 | 21.947 | 22.173 | 23.594 | 23.270 | 23.100 | 23.480 |
| May-88 | 28.691 | 28.197 | 28.383 | 27.607 | 26.640 | 27.491 | 28.391 | 28.320 | 27.900 | 27.900 |
| Jun-88 | 33.772 | 33.193 | 33.683 | 32.200 | 30.653 | 32.647 | 33.100 | 32.667 | 32.340 | 32.363 |
| Jul-88 | 34.008 | 33.110 | 33.898 | 32.047 | 30.423 | 32.737 | 33.249 | 33.020 | 32.875 | 32.043 |
| Aug-88 | 32.998 | 31.923 | 32.435 | 31.120 | 29.653 | 32.318 | 33.833 | 32.467 | 32.970 | 33.143 |
| Sep-88 | 28.517 | 27.867 | 28.073 | 27.000 | 26.023 | 27.580 | 28.873 | 28.137 | 28.065 | 28.480 |
| Oct-88 | 23.258 | 23.063 | 23.083 | 22.177 | 21.613 | 22.254 | 23.670 | 23.353 | 23.440 | 23.148 |
| Nov-88 | 14.544 | 14.990 | 14.645 | 14.063 | 14.207 | 13.509 | 15.834 | 15.767 | 15.880 | 15.978 |
| Dec-88 | 8.653 | 9.017 | 8.530 | 8.447 | 8.313 | 7.965 | 10.246 | 9.637 | 10.110 | 10.527 |
| Jan-89 | 9.649 | 9.997 | 9.445 | 9.267 | 9.413 | 8.836 | 11.116 | 10.747 | 10.915 | 11.303 |
| Feb-89 | 11.510 | 11.890 | 11.545 | 11.697 | 11.647 | 10.290 | 11.572 | 11.717 | 11.635 | 11.063 |
| Mar-89 | 18.595 | 19.323 | 19.083 | 18.290 | 18.120 | 17.725 | 18.388 | 18.727 | 18.470 | 17.863 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Apr-89 | 25.308 | 25.413 | 25.240 | 24.537 | 24.177 | 24.005 | 25.091 | 25.200 | 25.015 | 24.545 |
| May-89 | 31.208 | 30.883 | 30.868 | 30.143 | 29.260 | 30.178 | 31.624 | 31.177 | 31.260 | 31.055 |
| Jun-89 | 34.828 | 34.480 | 34.818 | 33.477 | 32.027 | 33.712 | 33.751 | 33.480 | 33.030 | 33.073 |
| Jul-89 | 36.103 | 35.293 | 35.775 | 34.417 | 32.983 | 35.103 | 35.670 | 35.073 | 35.015 | 35.243 |
| Aug-89 | 33.957 | 32.633 | 33.205 | 31.923 | 30.080 | 33.346 | 33.841 | 33.103 | 32.960 | 33.438 |
| Sep-89 | 28.368 | 27.040 | 27.565 | 26.563 | 25.597 | 27.761 | 29.072 | 28.140 | 28.540 | 28.625 |
| Oct-89 | 22.638 | 22.083 | 22.248 | 21.387 | 20.667 | 21.855 | 23.507 | 22.967 | 23.285 | 23.250 |
| Nov-89 | 14.220 | 14.457 | 14.230 | 13.690 | 13.613 | 13.115 | 15.304 | 15.127 | 15.220 | 15.168 |
| Dec-89 | 6.246 | 7.007 | 6.810 | 6.410 | 6.597 | 4.780 | 6.481 | 6.953 | 7.070 | 6.430 |
| Jan-90 | 9.782 | 10.270 | 9.690 | 9.490 | 9.640 | 8.925 | 11.153 | 11.000 | 11.180 | 11.083 |
| Feb-90 | 13.396 | 13.323 | 12.710 | 12.630 | 12.323 | 12.815 | 14.691 | 14.293 | 14.430 | 14.490 |
| Mar-90 | 18.533 | 18.473 | 18.157 | 17.743 | 17.640 | 17.640 | 19.113 | 18.587 | 18.715 | 18.615 |
| Apr-90 | 24.668 | 24.557 | 24.400 | 23.757 | 23.427 | 23.361 | 24.360 | 24.183 | 24.080 | 23.820 |
| May-90 | 29.386 | 29.007 | 29.075 | 28.377 | 27.237 | 28.185 | 29.176 | 29.030 | 28.775 | 28.453 |
| Jun-90 | 36.854 | 36.393 | 36.625 | 35.483 | 34.057 | 35.801 | 35.872 | 35.817 | 35.405 | 35.115 |
| Jul-90 | 33.293 | 32.557 | 33.185 | 31.607 | 30.230 | 32.135 | 31.934 | 31.737 | 31.300 | 30.627 |
| Aug-90 | 31.825 | 29.703 | 30.560 | 29.273 | 27.200 | 31.441 | 32.210 | 30.747 | 30.670 | 30.988 |
| Sep-90 | 27.933 | 25.997 | 27.005 | 25.380 | 23.773 | 27.795 | 27.976 | 26.677 | 26.690 | 27.068 |
| Oct-90 | 20.530 | 19.623 | 19.950 | 18.940 | 17.960 | 20.139 | 20.832 | 20.080 | 20.235 | 19.880 |
| Nov-90 | 14.758 | 14.470 | 14.190 | 13.840 | 13.560 | 14.055 | 15.818 | 15.050 | 15.290 | 15.455 |
| Dec-90 | 9.376 | 9.757 | 9.428 | 9.097 | 9.237 | 8.315 | 10.079 | 10.007 | 10.180 | 10.130 |
| Jan-91 | 7.975 | 8.440 | 7.995 | 7.853 | 8.230 | 7.008 | 8.913 | 8.800 | 8.920 | 8.645 |
| Feb-91 | 12.839 | 12.903 | 12.450 | 12.307 | 12.247 | 12.231 | 13.393 | 13.220 | 13.175 | 12.940 |
| Mar-91 | 17.708 | 17.730 | 17.335 | 16.750 | 16.597 | 17.135 | 18.708 | 17.893 | 18.205 | 18.535 |
| Apr-91 | 23.709 | 23.240 | 22.983 | 22.373 | 21.810 | 22.941 | 24.381 | 23.393 | 23.345 | 24.250 |
| May-91 | 30.389 | 29.777 | 29.745 | 29.243 | 28.087 | 29.648 | 30.893 | 30.327 | 30.015 | 30.175 |
| Jun-91 | 34.152 | 33.400 | 33.708 | 32.390 | 30.687 | 33.533 | 33.358 | 32.707 | 32.635 | 32.270 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Jul-91 | 32.930 | 31.510 | 31.953 | 30.733 | 28.870 | 32.275 | 33.316 | 32.213 | 32.350 | 32.375 |
| Aug-91 | 33.308 | 32.113 | 32.950 | 31.047 | 29.170 | 32.325 | 32.932 | 31.790 | 32.095 | 32.467 |
| Sep-91 | 26.339 | 25.353 | 25.713 | 24.627 | 23.610 | 25.713 | 26.316 | 25.670 | 25.465 | 25.700 |
| Oct-91 | 22.000 | 21.403 | 21.545 | 20.700 | 20.100 | 21.329 | 22.878 | 22.180 | 22.595 | 22.430 |
| Nov-91 | 11.247 | 11.157 | 10.712 | 10.840 | 10.843 | 10.336 | 12.087 | 11.870 | 11.985 | 11.883 |
| Dec-91 | 9.609 | 9.553 | 9.168 | 9.167 | 8.917 | 8.897 | 10.767 | 10.060 | 10.235 | 10.745 |
| Jan-92 | 7.803 | 7.890 | 7.480 | 7.213 | 7.353 | 7.025 | 8.820 | 8.373 | 8.710 | 8.788 |
| Feb-92 | 13.042 | 12.653 | 12.573 | 12.010 | 11.583 | 12.516 | 13.677 | 13.060 | 13.205 | 13.308 |
| Mar-92 | 18.046 | 17.947 | 17.698 | 17.087 | 16.823 | 17.620 | 18.327 | 17.620 | 17.725 | 17.962 |
| Apr-92 | 24.659 | 24.567 | 24.548 | 23.627 | 23.077 | 23.482 | 23.686 | 23.430 | 23.230 | 23.020 |
| May-92 | 27.222 | 26.707 | 27.795 | 25.900 | 24.903 | 26.112 | 26.334 | 25.820 | 25.875 | 25.633 |
| Jun-92 | 32.882 | 32.570 | 32.840 | 31.743 | 30.490 | 31.598 | 32.796 | 32.187 | 32.000 | 31.805 |
| Jul-92 | 34.453 | 33.930 | 34.675 | 32.893 | 31.447 | 32.859 | 32.807 | 32.820 | 32.440 | 31.800 |
| Aug-92 | 33.100 | 31.980 | 33.190 | 31.107 | 29.473 | 31.734 | 31.881 | 31.103 | 31.200 | 31.090 |
| Sep-92 | 29.488 | 28.537 | 29.425 | 27.590 | 26.497 | 28.717 | 29.587 | 28.310 | 28.790 | 29.525 |
| Oct-92 | 22.890 | 22.530 | 22.722 | 21.723 | 21.240 | 22.150 | 23.717 | 22.963 | 23.360 | 23.648 |
| Nov-92 | 11.962 | 11.740 | 11.705 | 10.983 | 10.777 | 11.137 | 12.994 | 12.277 | 12.620 | 12.978 |
| Dec-92 | 10.717 | 11.157 | 10.888 | 10.543 | 10.780 | 9.546 | 11.677 | 11.457 | 11.860 | 11.945 |
| Jan-93 | 10.192 | 10.630 | 10.200 | 9.997 | 10.230 | 9.108 | 10.908 | 10.727 | 10.920 | 10.640 |
| Feb-93 | 13.012 | 13.217 | 12.855 | 12.567 | 12.733 | 11.935 | 14.024 | 13.477 | 13.880 | 13.885 |
| Mar-93 | 17.903 | 18.117 | 17.840 | 17.223 | 17.163 | 16.920 | 18.470 | 17.763 | 18.175 | 18.458 |
| Apr-93 | 23.662 | 23.540 | 23.428 | 22.647 | 22.173 | 22.283 | 23.422 | 23.367 | 23.440 | 23.285 |
| May-93 | 29.422 | 28.940 | 29.410 | 28.180 | 26.980 | 28.007 | 28.954 | 28.700 | 28.695 | 28.455 |
| Jun-93 | 34.159 | 33.507 | 34.143 | 32.430 | 30.937 | 33.045 | 32.648 | 32.503 | 31.980 | 31.863 |
| Jul-93 | 35.476 | 33.903 | 34.715 | 32.903 | 31.187 | 34.908 | 35.177 | 34.163 | 34.425 | 34.113 |
| Aug-93 | 34.942 | 33.723 | 34.627 | 32.763 | 31.247 | 34.001 | 34.442 | 33.737 | 33.630 | 33.725 |
| Sep-93 | 28.879 | 27.787 | 28.393 | 26.867 | 25.770 | 28.106 | 28.571 | 28.143 | 28.020 | 27.815 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Oct-93 | 21.798 | 21.277 | 21.453 | 20.493 | 19.930 | 20.897 | 22.180 | 21.787 | 21.985 | 21.465 |
| Nov-93 | 13.360 | 13.830 | 13.363 | 13.160 | 13.440 | 11.975 | 13.949 | 14.090 | 14.160 | 13.755 |
| Dec-93 | 10.680 | 10.963 | 10.567 | 10.310 | 10.340 | 9.771 | 11.837 | 11.547 | 11.760 | 11.938 |
| Jan-94 | 9.449 | 10.097 | 9.587 | 9.293 | 9.513 | 8.393 | 10.261 | 10.523 | 10.430 | 10.185 |
| Feb-94 | 12.883 | 13.377 | 12.900 | 12.640 | 12.667 | 11.686 | 13.218 | 13.317 | 13.245 | 12.967 |
| Mar-94 | 18.784 | 18.647 | 18.532 | 17.870 | 17.503 | 17.875 | 19.088 | 18.587 | 18.585 | 18.873 |
| Apr-94 | 24.463 | 24.320 | 24.265 | 23.377 | 22.893 | 23.232 | 24.271 | 24.063 | 23.920 | 24.067 |
| May-94 | 30.304 | 29.560 | 29.893 | 29.040 | 28.360 | 28.886 | 29.910 | 29.777 | 29.500 | 28.978 |
| Jun-94 | 37.013 | 36.227 | 36.640 | 35.343 | 34.087 | 35.776 | 35.552 | 35.800 | 35.050 | 34.133 |
| Jul-94 | 36.726 | 35.923 | 36.717 | 34.833 | 33.730 | 35.477 | 35.338 | 34.990 | 34.670 | 34.263 |
| Aug-94 | 35.228 | 34.437 | 35.163 | 33.480 | 32.357 | 34.184 | 34.383 | 33.787 | 33.595 | 33.410 |
| Sep-94 | 28.969 | 28.170 | 29.092 | 27.117 | 26.540 | 28.473 | 29.026 | 27.917 | 28.205 | 28.337 |
| Oct-94 | 22.568 | 22.173 | 22.385 | 21.337 | 20.710 | 21.979 | 23.400 | 22.347 | 22.780 | 23.005 |
| Nov-94 | 15.540 | 15.700 | 15.230 | 15.030 | 15.100 | 14.533 | 16.703 | 16.360 | 16.515 | 16.470 |
| Dec-94 | 11.183 | 11.470 | 11.198 | 10.920 | 11.017 | 10.309 | 12.304 | 11.870 | 12.105 | 12.365 |
| Jan-95 | 9.400 | 9.773 | 9.420 | 9.043 | 9.243 | 8.530 | 10.038 | 10.137 | 10.215 | 9.885 |
| Feb-95 | 15.838 | 16.097 | 15.775 | 15.297 | 15.357 | 14.580 | 15.536 | 15.997 | 15.790 | 14.850 |
| Mar-95 | 18.082 | 18.393 | 18.088 | 17.603 | 17.583 | 16.874 | 18.029 | 18.117 | 18.120 | 17.363 |
| Apr-95 | 22.836 | 22.433 | 22.347 | 21.670 | 21.230 | 21.958 | 22.998 | 22.730 | 22.815 | 22.270 |
| May-95 | 29.011 | 28.970 | 28.998 | 28.067 | 27.583 | 27.588 | 29.137 | 28.837 | 28.755 | 28.415 |
| Jun-95 | 33.245 | 32.963 | 33.278 | 31.867 | 30.763 | 32.115 | 32.391 | 32.060 | 31.815 | 31.175 |
| Jul-95 | 35.683 | 35.107 | 35.475 | 34.000 | 32.763 | 34.725 | 34.979 | 34.670 | 34.620 | 33.735 |
| Aug-95 | 35.211 | 34.307 | 35.130 | 33.210 | 32.010 | 34.092 | 34.013 | 33.623 | 33.465 | 32.725 |
| Sep-95 | 29.652 | 28.590 | 28.893 | 27.927 | 27.197 | 28.660 | 30.082 | 29.543 | 29.310 | 29.340 |
| Oct-95 | 22.773 | 22.457 | 22.433 | 21.747 | 21.473 | 21.737 | 23.132 | 23.293 | 23.055 | 22.192 |
| Nov-95 | 15.228 | 15.303 | 15.190 | 14.743 | 14.707 | 14.105 | 15.439 | 15.863 | 15.575 | 14.885 |
| Dec-95 | 9.095 | 9.693 | 9.305 | 9.270 | 9.420 | 8.035 | 10.099 | 10.327 | 10.310 | 10.018 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Jan-96 | 8.181 | 9.093 | 8.553 | 8.250 | 8.850 | 7.155 | 8.708 | 9.327 | 9.220 | 8.640 |
| Feb-96 | 13.028 | 14.163 | 13.498 | 13.657 | 14.403 | 11.435 | 13.991 | 14.400 | 14.625 | 13.753 |
| Mar-96 | 15.553 | 15.913 | 15.705 | 15.097 | 15.143 | 14.502 | 15.336 | 15.617 | 15.335 | 14.983 |
| Apr-96 | 22.717 | 22.727 | 22.513 | 21.863 | 21.640 | 21.564 | 22.687 | 22.713 | 22.485 | 22.358 |
| May-96 | 32.632 | 32.387 | 32.187 | 31.690 | 30.937 | 31.522 | 32.844 | 32.933 | 32.380 | 31.925 |
| Jun-96 | 35.678 | 35.557 | 35.655 | 34.440 | 33.303 | 34.427 | 34.537 | 34.523 | 34.105 | 34.075 |
| Jul-96 | 35.848 | 35.023 | 35.123 | 34.273 | 33.060 | 34.506 | 35.576 | 35.313 | 35.135 | 34.933 |
| Aug-96 | 32.659 | 31.700 | 32.083 | 30.773 | 29.287 | 31.738 | 32.423 | 31.653 | 31.435 | 31.683 |
| Sep-96 | 27.712 | 26.730 | 27.217 | 25.970 | 24.807 | 27.017 | 28.037 | 26.967 | 27.100 | 27.625 |
| Oct-96 | 21.796 | 21.503 | 21.630 | 20.683 | 19.980 | 21.095 | 21.898 | 21.480 | 21.300 | 21.420 |
| Nov-96 | 14.373 | 14.557 | 14.135 | 13.790 | 13.760 | 13.612 | 15.462 | 15.177 | 15.245 | 15.160 |
| Dec-96 | 9.453 | 9.847 | 9.480 | 8.953 | 9.060 | 8.731 | 9.892 | 10.177 | 10.050 | 9.960 |
| Jan-97 | 6.666 | 6.503 | 6.160 | 6.253 | 6.080 | 6.019 | 8.156 | 7.627 | 8.100 | 7.892 |
| Feb-97 | 11.299 | 11.677 | 11.122 | 11.057 | 11.003 | 9.936 | 11.914 | 11.643 | 11.625 | 11.515 |
| Mar-97 | 18.761 | 18.877 | 18.710 | 18.133 | 17.737 | 17.984 | 18.488 | 18.223 | 18.060 | 17.748 |
| Apr-97 | 21.344 | 21.153 | 20.968 | 20.357 | 19.763 | 20.124 | 20.550 | 20.487 | 20.220 | 19.778 |
| May-97 | 29.062 | 28.553 | 29.018 | 27.970 | 26.973 | 27.399 | 28.176 | 28.157 | 27.580 | 27.150 |
| Jun-97 | 33.979 | 33.617 | 33.948 | 32.473 | 30.933 | 31.984 | 32.118 | 32.517 | 31.755 | 30.885 |
| Jul-97 | 35.667 | 34.893 | 35.608 | 33.790 | 32.090 | 34.128 | 34.638 | 34.437 | 34.085 | 33.570 |
| Aug-97 | 34.687 | 33.220 | 34.265 | 32.297 | 30.560 | 33.583 | 34.394 | 33.413 | 33.180 | 33.413 |
| Sep-97 | 30.835 | 29.907 | 30.638 | 28.890 | 28.007 | 29.756 | 30.614 | 30.087 | 29.655 | 30.233 |
| Oct-97 | 21.495 | 21.303 | 21.250 | 20.333 | 19.780 | 20.609 | 21.779 | 21.567 | 21.235 | 21.115 |
| Nov-97 | 13.055 | 13.480 | 13.208 | 12.893 | 13.100 | 11.920 | 13.963 | 13.940 | 13.940 | 13.933 |
| Dec-97 | 6.842 | 6.823 | 6.563 | 5.997 | 6.290 | 6.170 | 8.104 | 7.563 | 7.980 | 8.283 |
| Jan-98 | 10.521 | 11.080 | 10.563 | 10.100 | 10.437 | 9.519 | 11.650 | 11.640 | 11.815 | 11.650 |
| Feb-98 | 12.724 | 12.563 | 12.248 | 11.760 | 11.350 | 11.993 | 13.480 | 13.010 | 13.160 | 13.253 |
| Mar-98 | 16.584 | 16.753 | 16.475 | 15.850 | 15.730 | 15.649 | 17.032 | 16.527 | 16.620 | 16.708 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Apr-98 | 21.992 | 21.873 | 21.498 | 21.023 | 20.747 | 20.854 | 22.748 | 22.300 | 22.455 | 22.580 |
| May-98 | 30.991 | 30.670 | 30.500 | 29.993 | 29.213 | 29.747 | 32.330 | 31.883 | 32.150 | 32.165 |
| Jun-98 | 35.658 | 35.340 | 35.113 | 34.513 | 33.470 | 34.624 | 35.752 | 35.407 | 35.005 | 34.913 |
| Jul-98 | 37.843 | 36.540 | 37.185 | 35.707 | 34.210 | 36.929 | 37.406 | 36.870 | 36.555 | 36.655 |
| Aug-98 | 33.711 | 32.550 | 33.535 | 31.650 | 30.370 | 32.986 | 32.430 | 32.163 | 31.870 | 31.208 |
| Sep-98 | 32.000 | 30.873 | 31.440 | 30.010 | 29.103 | 31.552 | 31.490 | 31.083 | 30.870 | 30.445 |
| Oct-98 | 22.752 | 22.373 | 22.265 | 21.650 | 21.123 | 22.104 | 23.474 | 22.813 | 22.875 | 22.880 |
| Nov-98 | 15.628 | 15.627 | 15.288 | 14.933 | 14.820 | 14.760 | 16.608 | 16.017 | 16.165 | 16.485 |
| Dec-98 | 8.920 | 9.073 | 8.725 | 8.717 | 8.743 | 8.154 | 10.013 | 9.750 | 9.915 | 10.083 |
| Jan-99 | 10.302 | 10.723 | 10.358 | 9.880 | 10.117 | 9.557 | 10.974 | 11.290 | 11.255 | 10.935 |
| Feb-99 | 14.887 | 15.303 | 14.780 | 14.507 | 14.713 | 14.015 | 15.824 | 15.907 | 15.865 | 15.665 |
| Mar-99 | 18.873 | 19.127 | 18.880 | 18.303 | 18.197 | 17.729 | 19.246 | 18.933 | 19.040 | 18.988 |
| Apr-99 | 24.143 | 23.970 | 23.495 | 23.240 | 22.823 | 22.886 | 24.872 | 24.487 | 24.630 | 24.458 |
| May-99 | 29.277 | 29.127 | 29.075 | 28.423 | 27.683 | 27.960 | 30.396 | 29.503 | 29.310 | 29.858 |
| Jun-99 | 34.028 | 33.440 | 33.630 | 32.763 | 31.683 | 32.868 | 32.681 | 32.533 | 31.800 | 31.725 |
| Jul-99 | 34.734 | 32.877 | 33.708 | 32.503 | 30.567 | 33.797 | 33.436 | 33.440 | 32.875 | 32.195 |
| Aug-99 | 35.661 | 33.720 | 34.565 | 33.120 | 30.883 | 34.395 | 35.584 | 34.850 | 34.645 | 34.733 |
| Sep-99 | 30.830 | 30.103 | 30.435 | 29.103 | 27.877 | 29.563 | 30.830 | 30.070 | 29.995 | 30.478 |
| Oct-99 | 21.567 | 21.290 | 21.333 | 20.397 | 19.700 | 20.615 | 22.494 | 21.867 | 22.135 | 22.315 |
| Nov-99 | 15.603 | 15.837 | 15.698 | 14.970 | 14.720 | 14.589 | 16.570 | 16.480 | 16.475 | 16.645 |
| Dec-99 | 8.336 | 8.727 | 8.365 | 8.097 | 7.993 | 7.413 | 9.952 | 9.570 | 9.870 | 10.363 |
| Jan-00 | 10.396 | 11.147 | 10.643 | 10.390 | 10.837 | 9.417 | 11.514 | 11.550 | 11.680 | 11.752 |
| Feb-00 | 15.287 | 15.613 | 15.133 | 14.803 | 14.857 | 14.482 | 16.606 | 16.103 | 16.285 | 16.782 |
| Mar-00 | 19.455 | 19.610 | 19.187 | 18.810 | 18.580 | 18.475 | 20.782 | 19.947 | 20.410 | 21.018 |
| Apr-00 | 25.716 | 25.673 | 25.268 | 24.830 | 24.487 | 24.263 | 26.054 | 25.807 | 25.970 | 26.095 |
| May-00 | 31.872 | 31.770 | 31.775 | 30.967 | 30.177 | 30.408 | 32.581 | 32.157 | 32.445 | 32.407 |
| Jun-00 | 34.222 | 33.280 | 33.998 | 32.553 | 30.887 | 32.854 | 32.113 | 32.200 | 32.105 | 30.790 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Jul-00 | 36.640 | 35.630 | 36.035 | 34.757 | 32.997 | 35.276 | 35.684 | 35.370 | 35.270 | 34.868 |
| Aug-00 | 34.876 | 33.867 | 34.252 | 33.040 | 31.617 | 33.916 | 34.908 | 34.007 | 34.100 | 34.390 |
| Sep-00 | 30.926 | 30.420 | 30.500 | 29.510 | 28.443 | 29.761 | 31.288 | 30.973 | 30.970 | 31.128 |
| Oct-00 | 21.589 | 21.310 | 21.390 | 20.470 | 19.503 | 20.807 | 21.638 | 21.167 | 20.965 | 21.108 |
| Nov-00 | 11.524 | 11.760 | 11.385 | 11.167 | 11.020 | 10.380 | 12.263 | 12.170 | 12.245 | 11.873 |
| Dec-00 | 6.841 | 7.393 | 6.823 | 6.883 | 7.123 | 5.799 | 7.382 | 7.590 | 7.605 | 7.238 |

# Appendix G: NARR Monthly Relative Humidity Data

NARR monthly relative humidity data in percentage

| Date | Watershed | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 13070001 | 13070003 | 13070004 | 13070005 | 13070006 | 13070007 | 13070008 | 13070009 | 13070010 | 13070011 |
| Jan-81 | 57.58 | 56.297 | 56.298 | 58.2 | 57.177 | 59.063 | 59.155 | 57.523 | 59 | 59.555 |
| Feb-81 | 43.135 | 38.787 | 38.568 | 41.737 | 39.067 | 46.456 | 52.95 | 45.587 | 50.025 | 55.678 |
| Mar-81 | 43.8 | 41.127 | 41.208 | 43.293 | 41.29 | 45.961 | 50.363 | 46.357 | 48.83 | 52.388 |
| Apr-81 | 43.221 | 40.13 | 39.095 | 42.937 | 41.537 | 47.01 | 54.01 | 48.027 | 52.83 | 57.48 |
| May-81 | 35.748 | 33.763 | 31.905 | 35.38 | 35.83 | 40.2 | 48.817 | 41.84 | 47.765 | 53.693 |
| Jun-81 | 41.626 | 37.927 | 36.075 | 41.263 | 41.867 | 46.755 | 57.267 | 50.433 | 56.69 | 62.775 |
| Jul-81 | 41.923 | 40.313 | 40.685 | 42.41 | 43.887 | 44.266 | 47.711 | 45.21 | 48.49 | 52.015 |
| Aug-81 | 44.498 | 44.567 | 43.765 | 46.927 | 48.567 | 46.246 | 46.942 | 46.393 | 48.5 | 50.108 |
| Sep-81 | 49.064 | 49.083 | 48.788 | 51.05 | 51.223 | 50.652 | 50.088 | 49.1 | 50.58 | 52.638 |
| Oct-81 | 56.046 | 53.517 | 52.28 | 57.44 | 56.24 | 58.46 | 62.741 | 58.917 | 62.245 | 65.578 |
| Nov-81 | 38.285 | 34.6 | 34.635 | 37.557 | 34.42 | 41.706 | 47.275 | 38.397 | 42.365 | 49.985 |
| Dec-81 | 39.25 | 36.49 | 36.305 | 38.953 | 37.433 | 42.122 | 47.986 | 40.123 | 43.995 | 50.335 |
| Jan-82 | 40.141 | 36.44 | 38.33 | 39.14 | 37.457 | 43.766 | 44.708 | 37.433 | 40.885 | 46.875 |
| Feb-82 | 46.224 | 41.687 | 43.175 | 43.37 | 42.943 | 49.413 | 51.715 | 45.46 | 49.125 | 55.66 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Mar-82 | 31.537 | 28.573 | 28.943 | 30.767 | 29.587 | 34.797 | 43.841 | 35.623 | 40.865 | 48.108 |
| Apr-82 | 29.473 | 27.853 | 27.64 | 29.767 | 29.453 | 32.556 | 38.173 | 32.71 | 36.505 | 41.938 |
| May-82 | 38.338 | 35.43 | 33.833 | 37.983 | 37.857 | 42.895 | 49.033 | 43.313 | 48.13 | 53.795 |
| Jun-82 | 36.65 | 33.237 | 32.193 | 35.527 | 34.98 | 41.9 | 45.279 | 40.423 | 43.965 | 49.533 |
| Jul-82 | 36.187 | 34.023 | 34.43 | 36.59 | 37.8 | 39.263 | 40.711 | 38.127 | 40.615 | 44.19 |
| Aug-82 | 37.256 | 36.523 | 35.988 | 38.847 | 39.707 | 40.078 | 40.537 | 39.24 | 41.12 | 43.558 |
| Sep-82 | 39.027 | 38.13 | 38.12 | 41.043 | 41.707 | 41.191 | 42.939 | 40.67 | 43.42 | 45.068 |
| Oct-82 | 39.676 | 37.257 | 37.193 | 40.44 | 40.11 | 41.777 | 46.818 | 43.087 | 46.725 | 49.345 |
| Nov-82 | 45.573 | 42.96 | 44.633 | 45.663 | 44.957 | 48.478 | 50.86 | 45.533 | 49.455 | 53.4 |
| Dec-82 | 55.494 | 53.48 | 54.748 | 55.553 | 55.13 | 57.84 | 56.413 | 53.29 | 55.255 | 56.848 |
| Jan-83 | 56.876 | 51.027 | 52.79 | 53.5 | 50.347 | 61.168 | 57.449 | 52.27 | 54.205 | 58.433 |
| Feb-83 | 44.623 | 41.21 | 41.813 | 43.62 | 41.903 | 48.71 | 51.329 | 45.14 | 48.72 | 54.173 |
| Mar-83 | 33.307 | 31.87 | 32.165 | 34.35 | 34.103 | 36.055 | 40.716 | 35 | 38.74 | 43.79 |
| Apr-83 | 31.834 | 27.79 | 29.97 | 29.33 | 28.653 | 35.045 | 33.925 | 29.193 | 32.025 | 36.625 |
| May-83 | 27.105 | 24.347 | 23.613 | 25.853 | 25.667 | 31.6 | 36.735 | 30.297 | 34.965 | 41.003 |
| Jun-83 | 32.343 | 28.25 | 27.088 | 31.033 | 30.63 | 37.886 | 46.123 | 39.197 | 45.54 | 52.033 |
| Jul-83 | 35.358 | 33.81 | 32.528 | 36.587 | 38.097 | 39.194 | 44.71 | 40.797 | 44.92 | 49.523 |
| Aug-83 | 35.745 | 35.51 | 34.075 | 38.333 | 40.437 | 38.26 | 42.358 | 40.023 | 43.18 | 46.815 |
| Sep-83 | 41.258 | 39.453 | 38.313 | 42.737 | 43.55 | 43.884 | 48.652 | 45.43 | 49.7 | 52.048 |
| Oct-83 | 54.343 | 53.44 | 52.193 | 55.813 | 55.873 | 56.261 | 59.749 | 57.317 | 60.25 | 62.59 |
| Nov-83 | 46.01 | 42.81 | 42.635 | 45.763 | 44.01 | 49.673 | 52.309 | 45.3 | 48.09 | 54.73 |
| Dec-83 | 54.409 | 45.76 | 48.04 | 48.25 | 43.903 | 60.35 | 54.198 | 47.97 | 48.61 | 55.783 |
| Jan-84 | 59.692 | 51.617 | 54.465 | 54.153 | 50.567 | 62.879 | 62.085 | 55.943 | 59.045 | 64.86 |
| Feb-84 | 30.801 | 27.923 | 28.43 | 30.07 | 29.727 | 32.911 | 38.32 | 31.15 | 34.895 | 41.653 |
| Mar-84 | 30.091 | 24.763 | 25.4 | 26.953 | 25.237 | 33.191 | 39.737 | 31.99 | 36.45 | 43.245 |
| Apr-84 | 21.423 | 19.14 | 19.45 | 20.79 | 19.897 | 24.84 | 25.985 | 21.97 | 23.89 | 27.658 |
| May-84 | 34.038 | 31.28 | 30.713 | 32.883 | 32.99 | 37.32 | 37.755 | 35.19 | 37.11 | 40.113 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Jun-84 | 40.455 | 39.487 | 38.163 | 41.807 | 43.27 | 44.048 | 44.895 | 42.94 | 45.915 | 47.693 |
| Jul-84 | 36.254 | 35.62 | 34.66 | 38.247 | 40.69 | 39.536 | 40.177 | 38.153 | 40.455 | 43.233 |
| Aug-84 | 39.159 | 38.563 | 38.865 | 40.527 | 41.903 | 42.136 | 39.74 | 38.487 | 40.325 | 42.73 |
| Sep-84 | 44.599 | 43.96 | 43.005 | 46.143 | 47.663 | 46.863 | 48.245 | 47.25 | 49.8 | 50.503 |
| Oct-84 | 55.189 | 53.927 | 52.72 | 55.847 | 56.033 | 57.87 | 62.988 | 59.033 | 62.295 | 66.365 |
| Nov-84 | 48.891 | 45.31 | 44.65 | 48.017 | 45.647 | 52.126 | 57.977 | 50.683 | 54.825 | 60.31 |
| Dec-84 | 56.928 | 54.897 | 54.49 | 57.683 | 56.933 | 60.376 | 66.161 | 60.367 | 64.495 | 68.263 |
| Jan-85 | 55.702 | 53.183 | 52.813 | 55.397 | 54.887 | 59.305 | 58.775 | 53.607 | 55.81 | 60.735 |
| Feb-85 | 51.884 | 45.777 | 46.98 | 47.47 | 45.493 | 57.141 | 56.761 | 49.58 | 53.24 | 60.248 |
| Mar-85 | 41.935 | 38.637 | 37.713 | 41.617 | 40.103 | 44.687 | 51.478 | 45.673 | 50.055 | 54.928 |
| Apr-85 | 30.814 | 28.727 | 28.59 | 30.92 | 30.297 | 34.796 | 40.303 | 33.733 | 37.725 | 44.388 |
| May-85 | 30.903 | 29.077 | 28.163 | 30.503 | 31.22 | 35.22 | 41.81 | 34.923 | 39.785 | 46.755 |
| Jun-85 | 40.122 | 36.687 | 35.793 | 38.97 | 39.423 | 44.711 | 47.719 | 44.103 | 47.675 | 52.138 |
| Jul-85 | 35.609 | 34.71 | 33.875 | 36.963 | 38.467 | 38.97 | 42.796 | 38.903 | 41.995 | 47.203 |
| Aug-85 | 36.03 | 35.873 | 34.745 | 38.363 | 40.02 | 38.427 | 40.12 | 38.96 | 41.105 | 42.858 |
| Sep-85 | 46.43 | 45.483 | 44.278 | 48.483 | 49.977 | 49.268 | 51.356 | 49.253 | 51.8 | 54.578 |
| Oct-85 | 58.224 | 57.1 | 57.353 | 58.757 | 57.927 | 60.856 | 61.52 | 59.027 | 60.215 | 63.91 |
| Nov-85 | 43.179 | 38.563 | 39.088 | 42.513 | 39.29 | 47.796 | 56.477 | 45.063 | 50.97 | 60.928 |
| Dec-85 | 42.438 | 38.05 | 38.483 | 40.78 | 38.34 | 47.32 | 53.142 | 42.743 | 47.02 | 55.825 |
| Jan-86 | 40.998 | 36.96 | 37.268 | 39.81 | 38.143 | 43.795 | 47.107 | 40.117 | 43.41 | 49.448 |
| Feb-86 | 42.23 | 36.19 | 38.52 | 37.823 | 34.877 | 47.043 | 44.709 | 38.513 | 40.545 | 45.765 |
| Mar-86 | 30.233 | 27.073 | 27.32 | 29.917 | 28.777 | 33.129 | 36.655 | 31.84 | 34.56 | 38.08 |
| Apr-86 | 27.991 | 24.627 | 23.938 | 27.147 | 26.21 | 32.45 | 38.942 | 32.643 | 37.23 | 42.15 |
| May-86 | 31.079 | 28.193 | 27.413 | 30.15 | 29.773 | 35.92 | 45.25 | 37.06 | 43.035 | 50.648 |
| Jun-86 | 46.676 | 43.693 | 42.89 | 46.453 | 47.15 | 51.97 | 55.688 | 51.077 | 54.89 | 59.885 |
| Jul-86 | 37.123 | 36.187 | 36.838 | 38.417 | 38.827 | 40.643 | 40.28 | 37.13 | 39.245 | 43.368 |
| Aug-86 | 44.71 | 43.283 | 42.038 | 46.063 | 46.397 | 48.466 | 48.145 | 47.137 | 47.855 | 51.1 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Sep-86 | 53.48 | 51.803 | 50.993 | 54.513 | 54.073 | 56.845 | 57.038 | 54.87 | 56.05 | 59.443 |
| Oct-86 | 60.31 | 58.2 | 57.373 | 60.923 | 59.74 | 62.292 | 66.779 | 63.393 | 65.36 | 69.278 |
| Nov-86 | 53.805 | 52.41 | 52.735 | 55.05 | 53.617 | 56.122 | 57.831 | 53.977 | 56.315 | 59.988 |
| Dec-86 | 66.687 | 64.097 | 64.103 | 66.607 | 64.98 | 69.043 | 71.334 | 68.133 | 70.41 | 72.868 |
| Jan-87 | 51.916 | 46.51 | 47.513 | 48.18 | 45.34 | 55.312 | 54.491 | 48.717 | 50.48 | 56.53 |
| Feb-87 | 54.1 | 49.46 | 50.57 | 51.933 | 48.677 | 56.97 | 60.971 | 55.4 | 58.725 | 64.068 |
| Mar-87 | 42.539 | 36.987 | 37.703 | 40.05 | 36.33 | 45.506 | 51.476 | 44.403 | 48.415 | 53.713 |
| Apr-87 | 35.832 | 35.447 | 34.453 | 37.44 | 37.727 | 37.841 | 41.507 | 38.457 | 40.57 | 43.463 |
| May-87 | 41.015 | 38.667 | 36.095 | 41.11 | 42.123 | 46.067 | 51.437 | 47.187 | 51.41 | 55.3 |
| Jun-87 | 45.512 | 40.503 | 39.243 | 43.787 | 43.29 | 51.122 | 57.857 | 52.427 | 57.58 | 62.023 |
| Jul-87 | 41.888 | 39.397 | 37.325 | 43.16 | 44.76 | 46.706 | 52.041 | 48.47 | 52.795 | 56.748 |
| Aug-87 | 40.398 | 39.607 | 38.603 | 42.143 | 44.013 | 43.539 | 45.819 | 44.147 | 46.94 | 49.833 |
| Sep-87 | 44.894 | 43.87 | 42.913 | 46.743 | 47.507 | 47.484 | 51.653 | 48.787 | 52.085 | 53.713 |
| Oct-87 | 45.52 | 42.583 | 41.76 | 45.9 | 45.003 | 47.342 | 52.195 | 48.817 | 52.155 | 53.463 |
| Nov-87 | 42.017 | 39.203 | 39.298 | 41.99 | 40.77 | 44.39 | 51.821 | 44.763 | 49.905 | 54.295 |
| Dec-87 | 46.273 | 41.99 | 42.948 | 44.367 | 43.12 | 48.075 | 52.586 | 46.323 | 49.28 | 53.723 |
| Jan-88 | 44.649 | 39.683 | 40.82 | 42.853 | 39.76 | 47.686 | 52.392 | 45.477 | 49.845 | 53.983 |
| Feb-88 | 42.909 | 38.46 | 40.56 | 40.557 | 37.54 | 46.434 | 49.681 | 43.61 | 46.995 | 52.21 |
| Mar-88 | 28.377 | 24.8 | 24.978 | 27.047 | 24.973 | 31.209 | 36.923 | 31.227 | 34.845 | 39.128 |
| Apr-88 | 24.411 | 22.547 | 23.003 | 24.373 | 23.543 | 27.775 | 30.383 | 26.043 | 28.72 | 32.053 |
| May-88 | 32.774 | 29.793 | 28.605 | 31.627 | 31.52 | 37.236 | 42.653 | 37.717 | 42.23 | 45.41 |
| Jun-88 | 34.529 | 33.027 | 31.76 | 35.523 | 37.05 | 38.154 | 42.747 | 39.357 | 43.005 | 46.488 |
| Jul-88 | 43.077 | 41.63 | 40.635 | 44.597 | 46.033 | 47.145 | 48.863 | 45.757 | 48.18 | 53.173 |
| Aug-88 | 44.558 | 44.647 | 44.158 | 46.977 | 48.993 | 46.834 | 45.671 | 45.897 | 46.67 | 48.705 |
| Sep-88 | 43.307 | 41.14 | 40.36 | 43.947 | 44.067 | 46.707 | 50.07 | 46.193 | 49.695 | 52.218 |
| Oct-88 | 42.89 | 39.353 | 39.23 | 42.66 | 41.28 | 46.758 | 51.941 | 45.477 | 49.49 | 54.203 |
| Nov-88 | 30.127 | 26.823 | 27.37 | 29.66 | 27.753 | 33.23 | 40.886 | 30.46 | 35.56 | 43.56 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Dec-88 | 41.414 | 38.583 | 38.25 | 41.983 | 41.723 | 43.396 | 50.946 | 45.373 | 49.095 | 53.1 |
| Jan-89 | 37.024 | 35.107 | 34.75 | 38.277 | 38.383 | 39.366 | 48.969 | 41.213 | 46.47 | 52.258 |
| Feb-89 | 43.61 | 41.2 | 40.928 | 43.277 | 42.573 | 47.186 | 54.395 | 47.297 | 51.535 | 58.31 |
| Mar-89 | 32.539 | 27.47 | 27.495 | 30.487 | 28.68 | 35.727 | 43.301 | 35.15 | 39.265 | 46.395 |
| Apr-89 | 28.197 | 25.173 | 24.713 | 27.153 | 26.123 | 32.179 | 38.958 | 32.217 | 36.405 | 42.568 |
| May-89 | 27.797 | 24.843 | 23.928 | 26.613 | 25.847 | 32.183 | 39.142 | 32.307 | 36.605 | 43.02 |
| Jun-89 | 33.757 | 30.173 | 28.85 | 32.4 | 32.613 | 39.246 | 43.001 | 39.08 | 42.505 | 46.093 |
| Jul-89 | 30.843 | 30.007 | 29.575 | 32.217 | 33.24 | 34.052 | 35.833 | 33.457 | 35.56 | 38.333 |
| Aug-89 | 39.932 | 40.1 | 39.223 | 42.463 | 44.687 | 42.38 | 43.752 | 42.707 | 44.82 | 46.245 |
| Sep-89 | 42.607 | 43.28 | 43.203 | 44.587 | 45.153 | 43.878 | 42.391 | 42.04 | 42.375 | 44.225 |
| Oct-89 | 36.648 | 35.52 | 34.415 | 38.29 | 38.257 | 38.881 | 42.622 | 38.637 | 41.24 | 44.69 |
| Nov-89 | 33.508 | 32.777 | 32.043 | 35.567 | 35.993 | 35.608 | 43.882 | 36.073 | 40.37 | 47.29 |
| Dec-89 | 41.468 | 40.603 | 40.288 | 43.023 | 44.09 | 44.588 | 48.455 | 43.227 | 45.915 | 50.533 |
| Jan-90 | 36.393 | 34.06 | 34.51 | 36.62 | 36.15 | 38.876 | 43.566 | 37.41 | 40.84 | 46.17 |
| Feb-90 | 32.594 | 30.45 | 30.463 | 33.31 | 32.7 | 35.215 | 40.772 | 34.693 | 38.165 | 43.835 |
| Mar-90 | 37.831 | 35.073 | 34.043 | 38.077 | 36.663 | 41.454 | 50.211 | 43.8 | 48.7 | 55.06 |
| Apr-90 | 37.428 | 34.06 | 33.455 | 36.17 | 34.74 | 42.349 | 50.596 | 43.257 | 48.445 | 55.02 |
| May-90 | 28.647 | 26.31 | 25.093 | 28.103 | 28.257 | 32.881 | 41.385 | 34.27 | 39.19 | 46.288 |
| Jun-90 | 26.961 | 24.43 | 23.53 | 26.993 | 27.337 | 30.969 | 37.346 | 32.037 | 36.19 | 40.913 |
| Jul-90 | 44.378 | 43.957 | 43.015 | 46.503 | 48.243 | 47.559 | 50.69 | 48.73 | 51.43 | 55.093 |
| Aug-90 | 46.343 | 48.43 | 47.158 | 50.113 | 53.093 | 47.546 | 48.825 | 48.873 | 50.855 | 52.913 |
| Sep-90 | 54.947 | 56.77 | 55.128 | 58.693 | 60.53 | 55.376 | 58.863 | 58.267 | 60.235 | 61.793 |
| Oct-90 | 46.86 | 46.463 | 45.345 | 49.383 | 50.063 | 48.226 | 54.045 | 48.763 | 51.805 | 57.113 |
| Nov-90 | 50.324 | 48.973 | 48.335 | 52.12 | 51.46 | 52.472 | 59.626 | 53.433 | 57.96 | 62.385 |
| Dec-90 | 41.975 | 40.9 | 40.238 | 44.157 | 44.067 | 43.821 | 51.051 | 44.623 | 47.945 | 52.96 |
| Jan-91 | 60.266 | 57.27 | 57.53 | 59.577 | 57.67 | 62.951 | 66.099 | 61.13 | 63.655 | 68.855 |
| Feb-91 | 43.151 | 40.683 | 41.455 | 43.37 | 41.723 | 44.259 | 49.2 | 44.027 | 47.255 | 51.735 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Mar-91 | 30.808 | 29.083 | 29.113 | 31.957 | 30.877 | 32.302 | 36.349 | 32.693 | 34.575 | 38.495 |
| Apr-91 | 27.243 | 25.557 | 25.233 | 27.65 | 27.06 | 29.816 | 36.895 | 30.647 | 34.98 | 40.798 |
| May-91 | 31.228 | 28.447 | 27.043 | 30.337 | 30.54 | 35.547 | 44.121 | 37.62 | 43.315 | 49.06 |
| Jun-91 | 35.421 | 32.137 | 31.005 | 34.74 | 35.007 | 40.146 | 47.571 | 42.407 | 46.715 | 52.27 |
| Jul-91 | 44.44 | 44.623 | 44.228 | 46.793 | 49.02 | 46.986 | 47.527 | 46.56 | 48.07 | 50.618 |
| Aug-91 | 44.758 | 44.357 | 43.428 | 46.803 | 48.42 | 48.099 | 47.51 | 47.06 | 47.61 | 48.925 |
| Sep-91 | 58.245 | 57.367 | 57.328 | 59.39 | 59.35 | 60.339 | 61.662 | 59.883 | 62.38 | 63.855 |
| Oct-91 | 42.122 | 40.113 | 39.515 | 42.483 | 41.367 | 44.608 | 50.727 | 43.97 | 47.52 | 54.1 |
| Nov-91 | 50.978 | 48.343 | 49.435 | 50.397 | 48.293 | 54.255 | 57.961 | 51.303 | 54.745 | 60.135 |
| Dec-91 | 61.917 | 59.8 | 60.16 | 62.587 | 61.19 | 63.86 | 68.555 | 63.68 | 67.005 | 70.478 |
| Jan-92 | 58.585 | 56.62 | 57.185 | 59.867 | 58.027 | 60.182 | 63.687 | 58.71 | 61.34 | 65.213 |
| Feb-92 | 47.893 | 46.507 | 46.233 | 48.983 | 48.047 | 49.329 | 55.373 | 49.907 | 53.13 | 58.15 |
| Mar-92 | 35.59 | 32.407 | 32.575 | 35.567 | 33.453 | 37.9 | 45.068 | 38.74 | 42.11 | 47.848 |
| Apr-92 | 37.154 | 32.94 | 31.993 | 35.963 | 34.307 | 42.373 | 51.492 | 43.763 | 49.16 | 55.24 |
| May-92 | 48.493 | 46.56 | 44.16 | 48.793 | 48.86 | 51.986 | 57.852 | 53.4 | 56.76 | 61.548 |
| Jun-92 | 40.6 | 34.467 | 34.038 | 36.68 | 33.733 | 46.682 | 50.729 | 44.437 | 48.48 | 54.685 |
| Jul-92 | 39.85 | 37.353 | 36.313 | 40.003 | 40.7 | 44.566 | 49.641 | 45.003 | 48.815 | 53.23 |
| Aug-92 | 43.903 | 42.9 | 41.128 | 45.6 | 46.82 | 47.893 | 49.637 | 48.147 | 49.815 | 52.298 |
| Sep-92 | 42.693 | 41.08 | 39.648 | 44.017 | 44.013 | 45.091 | 48.21 | 45.997 | 47.965 | 50 |
| Oct-92 | 40.073 | 37.56 | 36.98 | 40.2 | 39.257 | 42.576 | 46.168 | 42.053 | 44.45 | 47.365 |
| Nov-92 | 42.996 | 40.467 | 39.203 | 43.857 | 42.097 | 46.19 | 51.808 | 46.72 | 49.32 | 53.255 |
| Dec-92 | 49.1 | 47.29 | 46.01 | 50.83 | 50.47 | 52.736 | 59.709 | 53.333 | 56.545 | 61.635 |
| Jan-93 | 55.831 | 53.373 | 53.978 | 56.4 | 54.313 | 58.423 | 58.482 | 55.58 | 56.56 | 60.318 |
| Feb-93 | 44.4 | 41.983 | 42.06 | 44.41 | 42.653 | 47.65 | 51.11 | 46.853 | 48.865 | 53.215 |
| Mar-93 | 36.313 | 33.493 | 33.583 | 35.853 | 33.897 | 39.566 | 43.562 | 39.377 | 41.435 | 45.885 |
| Apr-93 | 27.811 | 24.907 | 24.52 | 27.027 | 25.8 | 32.116 | 36.699 | 30.643 | 33.975 | 39.705 |
| May-93 | 31.058 | 27.983 | 26.47 | 30.4 | 30.177 | 36.325 | 42.893 | 37.047 | 41.225 | 46.53 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Jun-93 | 37.155 | 35.007 | 33.155 | 38.327 | 39.243 | 41.653 | 50.098 | 44.963 | 50.145 | 54.558 |
| Jul-93 | 39.635 | 39.547 | 38.373 | 42.467 | 44.23 | 42.561 | 45.829 | 43.937 | 46.46 | 49.643 |
| Aug-93 | 37.098 | 36.887 | 35.845 | 39.247 | 40.667 | 39.847 | 41.907 | 39.947 | 42.24 | 45.028 |
| Sep-93 | 45.324 | 45.167 | 43.313 | 48.733 | 49.833 | 47.596 | 53.213 | 49.713 | 53.015 | 56.115 |
| Oct-93 | 40.463 | 39.063 | 38.175 | 41.913 | 41.097 | 43.443 | 48.79 | 43.167 | 45.97 | 52.195 |
| Nov-93 | 39.41 | 38.503 | 38.525 | 41.673 | 41.697 | 42.115 | 47.827 | 41.583 | 45.395 | 50.285 |
| Dec-93 | 40.428 | 40.28 | 38.823 | 43.187 | 44.443 | 42.274 | 49.57 | 44.85 | 48.66 | 51.468 |
| Jan-94 | 41.608 | 38.123 | 37.538 | 41.437 | 39.91 | 45.421 | 53.325 | 44.67 | 49.74 | 56.203 |
| Feb-94 | 36.082 | 32.56 | 31.933 | 36.007 | 34.973 | 39.648 | 49.426 | 39.973 | 45.72 | 52.795 |
| Mar-94 | 36.61 | 35.567 | 34.825 | 38.027 | 38.043 | 39.044 | 45.962 | 40.733 | 44.51 | 48.825 |
| Apr-94 | 29.208 | 26.58 | 25.718 | 28.793 | 28.207 | 33.545 | 42.129 | 34.813 | 39.635 | 46.295 |
| May-94 | 40.501 | 37.607 | 36.703 | 39.05 | 37.723 | 46.251 | 51.542 | 45.177 | 49.585 | 56.398 |
| Jun-94 | 30.477 | 28.293 | 26.685 | 30.947 | 31.547 | 34.752 | 42.755 | 36.927 | 41.995 | 48.303 |
| Jul-94 | 30.945 | 29.343 | 28.453 | 31.807 | 32.17 | 34.341 | 38.943 | 35.48 | 38.775 | 42.708 |
| Aug-94 | 36.299 | 35.46 | 34.268 | 38.08 | 39.007 | 39.325 | 42.41 | 40.223 | 42.88 | 46.563 |
| Sep-94 | 41.958 | 41.133 | 39.633 | 43.767 | 42.993 | 43.39 | 45.361 | 44.153 | 45.495 | 47.99 |
| Oct-94 | 42.996 | 39.74 | 38.658 | 42.833 | 40.77 | 46.134 | 54.775 | 48.277 | 52.535 | 58.938 |
| Nov-94 | 41.288 | 38.043 | 38.205 | 41.363 | 39.347 | 45.115 | 53.309 | 43.803 | 49.155 | 58.18 |
| Dec-94 | 49.187 | 46.82 | 46.348 | 49.643 | 48.137 | 52.081 | 60.595 | 53.307 | 57.945 | 64.01 |
| Jan-95 | 45.397 | 42.003 | 43.145 | 44.5 | 41.343 | 48.264 | 50.745 | 43.907 | 45.775 | 53.075 |
| Feb-95 | 39.866 | 38.433 | 38.925 | 41.003 | 40.033 | 42.624 | 45.765 | 40.513 | 43.215 | 49.258 |
| Mar-95 | 36.633 | 34.263 | 34.64 | 36.653 | 35.58 | 40.08 | 45.739 | 39.45 | 43.19 | 50.333 |
| Apr-95 | 27.663 | 25.76 | 24.895 | 27.277 | 26.773 | 31.197 | 40.446 | 32.317 | 37.05 | 45.288 |
| May-95 | 30.623 | 26.273 | 25.325 | 28.733 | 26.877 | 36.156 | 41.893 | 35.307 | 39.72 | 45.968 |
| Jun-95 | 35.098 | 32.067 | 30.083 | 35.13 | 35.427 | 39.966 | 47.828 | 42.633 | 47.435 | 52.703 |
| Jul-95 | 31.833 | 29.997 | 29.088 | 32.73 | 33.33 | 35.24 | 40.059 | 35.777 | 38.75 | 44.48 |
| Aug-95 | 41.12 | 40.86 | 39.048 | 43.887 | 45.25 | 44.999 | 47.645 | 46 | 48.065 | 51.903 |

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| Sep-95 | 48.888 | 48.377 | 47.715 | 50.427 | 50.257 | 52.338 | 53.365 | 50.823 | 53.765 | 56.325 |
| Oct-95 | 35.718 | 33.513 | 32.875 | 35.967 | 35.003 | 38.815 | 44.827 | 37.663 | 42.21 | 48.59 |
| Nov-95 | 43.442 | 42.317 | 41.665 | 44.44 | 44.243 | 46.421 | 55.417 | 46.23 | 52.335 | 59.753 |
| Dec-95 | 46.965 | 45.147 | 45.785 | 46.123 | 44.927 | 49.77 | 54.796 | 46.89 | 50.61 | 58.738 |
| Jan-96 | 37.762 | 34.317 | 35.978 | 36.117 | 33.173 | 39.797 | 42.229 | 34.997 | 37.735 | 43.98 |
| Feb-96 | 34.865 | 32.057 | 33.033 | 33.363 | 31.707 | 37.711 | 40.812 | 35.09 | 37.605 | 43.218 |
| Mar-96 | 26.346 | 23.577 | 23.728 | 25.837 | 24.3 | 29.267 | 37.063 | 29.28 | 33.92 | 40.093 |
| Apr-96 | 23.801 | 21.88 | 22.308 | 23.627 | 22.49 | 26.301 | 30.369 | 24.853 | 28.2 | 33.483 |
| May-96 | 23.648 | 19.307 | 17.988 | 21.72 | 20.503 | 28.966 | 39.309 | 30.657 | 37.37 | 44.33 |
| Jun-96 | 33.109 | 30.01 | 29.888 | 32.69 | 32.837 | 37.228 | 40.686 | 36.717 | 40.035 | 43.65 |
| Jul-96 | 35.488 | 34.29 | 34.838 | 36.353 | 37.567 | 38.785 | 39.685 | 37.3 | 39.77 | 42.898 |
| Aug-96 | 44.22 | 43.51 | 43.07 | 46.09 | 47.567 | 47.601 | 49.35 | 47.683 | 50.195 | 52.473 |
| Sep-96 | 48.646 | 47.007 | 45.878 | 49.663 | 49.833 | 51.641 | 56.412 | 52.907 | 55.975 | 59.103 |
| Oct-96 | 43.431 | 40.533 | 40.103 | 43.723 | 43.163 | 46.34 | 53.471 | 46.633 | 51.355 | 56.63 |
| Nov-96 | 45.118 | 40.413 | 40.215 | 43.817 | 41.003 | 48.78 | 59.069 | 49.23 | 55.135 | 62.91 |
| Dec-96 | 35.706 | 33.233 | 33.545 | 36.563 | 35.58 | 37.894 | 49.599 | 37.577 | 43.91 | 52.32 |
| Jan-97 | 54.151 | 52.92 | 54.505 | 54.043 | 52.987 | 55.494 | 55.1 | 51.2 | 52.07 | 57.118 |
| Feb-97 | 52.404 | 48.223 | 48.94 | 50.133 | 47.87 | 56.593 | 59.296 | 54.347 | 57.67 | 62.005 |
| Mar-97 | 36.548 | 34.187 | 33.38 | 36.707 | 36.38 | 38.697 | 48.291 | 41.433 | 46.14 | 52.99 |
| Apr-97 | 42.758 | 39.48 | 38.91 | 42.167 | 40.823 | 47.252 | 53.39 | 48.027 | 51.795 | 57.135 |
| May-97 | 39.433 | 36.403 | 35.248 | 38.227 | 37.8 | 44.944 | 50.757 | 44.147 | 49.27 | 55.615 |
| Jun-97 | 40.109 | 36.213 | 34.943 | 39.087 | 39.307 | 46.521 | 53.083 | 46.687 | 52.11 | 57.983 |
| Jul-97 | 37.422 | 36.077 | 34.97 | 38.933 | 40.85 | 41.812 | 45.126 | 41.813 | 45.08 | 49.245 |
| Aug-97 | 39.112 | 39.017 | 37.33 | 41.623 | 43.363 | 42.82 | 45.307 | 43.22 | 46.21 | 48.925 |
| Sep-97 | 45.413 | 44.027 | 43.48 | 46.727 | 46.503 | 47.997 | 48.891 | 46.85 | 49.435 | 50.575 |
| Oct-97 | 42.513 | 39.4 | 39.325 | 42.407 | 41.567 | 46.166 | 51.263 | 44.733 | 49.39 | 54.588 |
| Nov-97 | 45.077 | 41.923 | 42.003 | 44.69 | 42.693 | 48.594 | 54.351 | 46.033 | 50.83 | 56.758 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Dec-97 | 51.008 | 48.02 | 49.245 | 50.727 | 46.803 | 54.221 | 54.012 | 49.793 | 50.545 | 54.553 |
| Jan-98 | 43.746 | 38.743 | 39.975 | 42.423 | 38.517 | 48.286 | 52.711 | 44.003 | 47.88 | 55.133 |
| Feb-98 | 40.466 | 37.507 | 38.16 | 40.39 | 38.32 | 44.736 | 47.907 | 41.553 | 44.16 | 50.465 |
| Mar-98 | 33.914 | 30.24 | 30.58 | 33.11 | 30.967 | 37.755 | 44.683 | 37.257 | 41.31 | 48.323 |
| Apr-98 | 26.198 | 24.473 | 24.633 | 26.48 | 25.933 | 29.583 | 32.742 | 28.33 | 31.03 | 35.518 |
| May-98 | 19.628 | 17.483 | 16.905 | 19.213 | 18.657 | 23.476 | 29.663 | 23.533 | 27.3 | 32.868 |
| Jun-98 | 24.789 | 23.033 | 21.885 | 25.197 | 25.833 | 28.096 | 37.093 | 31.283 | 36.43 | 41.97 |
| Jul-98 | 31.21 | 31.103 | 30.03 | 33.363 | 34.837 | 33.829 | 37.155 | 34.907 | 37.635 | 40.385 |
| Aug-98 | 43.006 | 43.433 | 41.375 | 46.017 | 47.66 | 45.221 | 51.772 | 48.783 | 52.26 | 56.405 |
| Sep-98 | 41.769 | 41.467 | 39.718 | 44.593 | 45.383 | 44.048 | 52.399 | 47.683 | 51.915 | 57.26 |
| Oct-98 | 50.846 | 48.34 | 47.598 | 51.43 | 50.87 | 53.218 | 62.093 | 56.09 | 61.4 | 66.293 |
| Nov-98 | 50.34 | 46.103 | 46.115 | 49.37 | 47.11 | 54.289 | 64.291 | 54.313 | 60.815 | 68.08 |
| Dec-98 | 49.763 | 46.197 | 46.895 | 48.457 | 45.75 | 52.821 | 58.301 | 50.763 | 54.665 | 60.863 |
| Jan-99 | 37.777 | 34.367 | 35.218 | 36.403 | 33.367 | 40.539 | 46.137 | 36.69 | 40.64 | 49.193 |
| Feb-99 | 27.56 | 24.183 | 24.268 | 26.387 | 24.567 | 30.211 | 39.788 | 29.86 | 35.495 | 43.41 |
| Mar-99 | 38.073 | 33.607 | 33.238 | 35.727 | 33.627 | 43.13 | 50.315 | 43.363 | 47.96 | 53.713 |
| Apr-99 | 26.675 | 24.79 | 23.878 | 27.047 | 27.013 | 30.107 | 39.563 | 32.007 | 37.28 | 43.873 |
| May-99 | 31.813 | 27.17 | 26.463 | 29.177 | 27.627 | 37.156 | 44.765 | 37.767 | 43.645 | 49.388 |
| Jun-99 | 39.872 | 36.887 | 34.658 | 39.62 | 40.36 | 44.686 | 52.636 | 48.487 | 53.85 | 56.818 |
| Jul-99 | 40.639 | 41.583 | 40.063 | 43.463 | 46.387 | 43.458 | 49.612 | 46.283 | 50.275 | 54.445 |
| Aug-99 | 34.365 | 35.21 | 33.815 | 37.333 | 40.143 | 37.595 | 40.083 | 37.727 | 40.555 | 43.545 |
| Sep-99 | 40.914 | 39.703 | 39.125 | 42.74 | 43.857 | 44.531 | 46.439 | 44.383 | 47.185 | 48.648 |
| Oct-99 | 36.393 | 33.873 | 33.308 | 36.7 | 36.137 | 39.756 | 44.165 | 39.433 | 42.415 | 46.273 |
| Nov-99 | 38.467 | 35.76 | 35.715 | 38.573 | 37.673 | 42.016 | 47.027 | 40.287 | 43.795 | 49.15 |
| Dec-99 | 39.924 | 38.097 | 38.688 | 40.133 | 40.13 | 42.372 | 43.911 | 39.59 | 42.33 | 44.838 |
| Jan-00 | 38.129 | 34.25 | 34.665 | 36.723 | 34.923 | 41.556 | 46.118 | 39.467 | 42.99 | 47.655 |
| Feb-00 | 32.187 | 29.51 | 29.1 | 32.137 | 30.873 | 34.686 | 43.512 | 35.89 | 40.48 | 46.538 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Mar-00 | 29.54 | 25.157 | 25.108 | 27.683 | 25.59 | 34.457 | 39.738 | 33.383 | 37.005 | 42.083 |
| Apr-00 | 28.107 | 24.937 | 24.29 | 27.113 | 25.953 | 33.094 | 38.687 | 32.507 | 36.095 | 41.668 |
| May-00 | 25.577 | 22.387 | 21.245 | 24.683 | 23.913 | 30.659 | 40.273 | 32.14 | 37.805 | 45.148 |
| Jun-00 | 43.615 | 41.77 | 39.938 | 44.4 | 45.617 | 48.611 | 54.109 | 50.31 | 53.535 | 58.935 |
| Jul-00 | 30.052 | 29.017 | 29.09 | 31 | 32.38 | 33.416 | 36.086 | 32.76 | 35.185 | 39.31 |
| Aug-00 | 33.259 | 33.217 | 32.218 | 35.56 | 37.5 | 35.774 | 39.289 | 37.427 | 39.82 | 42.378 |
| Sep-00 | 29.538 | 28.44 | 28.01 | 30.877 | 31.7 | 32.16 | 36.699 | 32.487 | 35.545 | 39.025 |
| Oct-00 | 55.657 | 53.227 | 51.418 | 56.623 | 57.21 | 58.166 | 65.571 | 61.503 | 66.295 | 69.193 |
| Nov-00 | 54.203 | 50.093 | 49.803 | 52.893 | 51.683 | 58.656 | 64.942 | 57.25 | 62.1 | 68.725 |
| Dec-00 | 51.89 | 48.637 | 49.543 | 50.227 | 48.46 | 55.836 | 61.636 | 53.07 | 57.615 | 64.465 |

# Appendix H: NARR Monthly Wind Speed Data

NARR monthly wind speed data in m/s

| Date | Watershed | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 13070001 | 13070003 | 13070004 | 13070005 | 13070006 | 13070007 | 13070008 | 13070009 | 13070010 | 13070011 |
| Jan-81 | 2.503746 | 0.89754 | 1.000803 | 2.117863 | 1.259006 | 0.769631 | 1.361393 | 0.420127 | 0.901255 | 0.784336 |
| Feb-81 | 0.759593 | 1.942563 | 1.24722 | 1.397571 | 2.723188 | 2.790955 | 2.573629 | 1.313307 | 1.643194 | 0.260854 |
| Mar-81 | 2.789589 | 2.455512 | 2.106747 | 2.179527 | 2.808012 | 2.029528 | 1.940259 | 1.680088 | 1.43315 | 1.956567 |
| Apr-81 | 0.517287 | 1.399968 | 1.428619 | 1.27542 | 0.837914 | 0.107802 | 1.075938 | 0.760986 | 0.734115 | 1.317788 |
| May-81 | 0.851933 | 1.359008 | 1.320137 | 1.677014 | 1.183545 | 0.639324 | 1.022049 | 0.720289 | 0.939474 | 1.35144 |
| Jun-81 | 2.817968 | 1.970706 | 1.783741 | 1.339705 | 1.215763 | 2.690955 | 2.885954 | 3.298948 | 3.041253 | 3.350829 |
| Jul-81 | 2.81133 | 2.210597 | 2.218731 | 1.980076 | 1.878631 | 2.677173 | 2.965491 | 3.187615 | 3.404875 | 2.949962 |
| Aug-81 | 2.774907 | 2.326611 | 2.311854 | 2.347741 | 1.83909 | 3.057542 | 2.421726 | 2.58331 | 2.569952 | 2.418067 |
| Sep-81 | 1.70235 | 1.159968 | 1.389106 | 0.890469 | 0.694321 | 1.616887 | 1.943731 | 2.000733 | 1.831192 | 2.229886 |
| Oct-81 | 0.605248 | 0.312101 | 0.717177 | 0.746995 | 0.705344 | 1.153147 | 1.4156 | 1.016867 | 1.133473 | 1.529418 |
| Nov-81 | 0.836732 | 1.566753 | 2.200251 | 2.147853 | 1.582187 | 1.196662 | 0.808954 | 0.899807 | 1.270949 | 1.130597 |
| Dec-81 | 1.220649 | 1.864186 | 2.333838 | 2.491037 | 1.939052 | 1.306156 | 0.913873 | 1.172585 | 1.311259 | 0.124179 |
| Jan-82 | 1.484517 | 2.739264 | 3.461288 | 3.875636 | 3.133741 | 2.927897 | 1.1893 | 1.625328 | 2.246213 | 1.376106 |
| Feb-82 | 1.557842 | 1.960608 | 2.359294 | 1.136732 | 0.963871 | 1.916436 | 1.225221 | 1.161943 | 1.24466 | 1.673317 |
| Mar-82 | 4.705133 | 2.249531 | 3.110904 | 2.854314 | 2.459045 | 2.042194 | 2.237257 | 2.557041 | 2.110312 | 2.079031 |
| Apr-82 | 3.00306 | 2.608515 | 2.950085 | 3.461808 | 3.483287 | 2.704467 | 2.596501 | 3.231235 | 3.113906 | 3.218639 |

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|---|---|---|---|---|---|---|---|---|---|---|
| May-82 | 2.03785 | 3.145642 | 2.577911 | 2.64273 | 3.384547 | 2.484598 | 3.017978 | 2.159034 | 2.814798 | 2.725459 |
| Jun-82 | 2.199059 | 2.395659 | 2.037227 | 2.238287 | 1.821601 | 2.643485 | 2.77881 | 2.743033 | 2.245788 | 2.655493 |
| Jul-82 | 3.378439 | 2.791894 | 2.564685 | 1.941541 | 2.187519 | 2.370953 | 2.453899 | 3.278401 | 2.859792 | 3.112441 |
| Aug-82 | 2.270359 | 1.668356 | 1.129016 | 1.194311 | 2.011788 | 2.151698 | 2.27981 | 3.336862 | 2.731007 | 3.560934 |
| Sep-82 | 1.404268 | 1.629273 | 1.134851 | 1.259918 | 2.015622 | 1.906716 | 2.669729 | 2.700972 | 2.234194 | 2.108427 |
| Oct-82 | 1.010149 | 0.873604 | 0.547434 | 0.737699 | 0.808225 | 1.054691 | 1.493227 | 1.514776 | 1.340383 | 1.657217 |
| Nov-82 | 0.72718 | 1.476062 | 1.647647 | 1.486852 | 1.14007 | 0.554745 | 0.201776 | 0.392412 | 0.406943 | 0.472421 |
| Dec-82 | 1.108624 | 1.269459 | 1.577182 | 1.761915 | 1.355336 | 1.248246 | 0.399471 | 1.54395 | 1.375934 | 0.487782 |
| Jan-83 | 0.873307 | 1.404034 | 1.781647 | 1.707484 | 1.391789 | 1.510255 | 0.87 | 0.973557 | 0.512842 | 0.053346 |
| Feb-83 | 1.122672 | 1.507295 | 1.901352 | 2.458615 | 2.019294 | 0.913556 | 0.391985 | 1.11433 | 0.791202 | 0.201902 |
| Mar-83 | 2.829254 | 3.397239 | 3.625347 | 3.99837 | 3.546058 | 2.237832 | 1.628017 | 2.14183 | 2.011865 | 1.774875 |
| Apr-83 | 1.938547 | 2.457532 | 2.294159 | 2.701566 | 2.235071 | 1.845713 | 1.625029 | 1.718015 | 1.849701 | 1.638725 |
| May-83 | 1.654447 | 1.922652 | 2.212833 | 2.382151 | 2.283561 | 1.587941 | 1.924347 | 2.004496 | 1.726627 | 2.559307 |
| Jun-83 | 1.220432 | 1.012517 | 1.748741 | 1.651372 | 1.831899 | 2.171447 | 3.327012 | 2.739695 | 2.734783 | 3.205607 |
| Jul-83 | 2.883859 | 2.398626 | 2.018163 | 2.442589 | 1.496923 | 2.571767 | 2.927227 | 3.075798 | 2.840968 | 2.749903 |
| Aug-83 | 2.283951 | 1.739343 | 1.586148 | 1.647243 | 1.237956 | 2.235724 | 2.339303 | 2.58395 | 2.001484 | 2.168174 |
| Sep-83 | 2.358438 | 1.538393 | 1.376298 | 1.191469 | 1.216259 | 2.216441 | 2.373641 | 2.671661 | 2.370351 | 2.636164 |
| Oct-83 | 0.70491 | 0.127017 | 0.278062 | 0.83492 | 0.238107 | 0.784228 | 1.467374 | 1.37494 | 1.27751 | 1.736401 |
| Nov-83 | 1.441278 | 2.381066 | 2.894069 | 3.28201 | 2.675555 | 1.702483 | 1.363727 | 1.430228 | 1.415877 | 0.547197 |
| Dec-83 | 1.463414 | 2.3759 | 2.738565 | 3.445351 | 1.674736 | 0.224167 | 0.990344 | 0.960764 | 0.413661 | 0.441721 |
| Jan-84 | 1.203504 | 0.61218 | 0.448052 | 1.624859 | 1.176107 | 0.590888 | 0.962644 | 0.982039 | 0.810408 | 1.197157 |
| Feb-84 | 1.48912 | 2.013461 | 2.360165 | 2.642247 | 2.312303 | 2.322606 | 1.465202 | 1.703938 | 1.922301 | 1.469529 |
| Mar-84 | 2.231335 | 3.165523 | 3.755108 | 3.398041 | 3.153627 | 3.252978 | 2.812922 | 2.997823 | 2.684599 | 2.743746 |
| Apr-84 | 3.863643 | 3.691674 | 4.19134 | 4.066065 | 3.833393 | 3.093645 | 2.672929 | 2.633237 | 2.619448 | 1.890449 |
| May-84 | 2.332512 | 2.080301 | 1.716877 | 1.908116 | 1.951129 | 1.782969 | 1.901857 | 1.545785 | 2.667776 | 2.733143 |
| Jun-84 | 2.707628 | 1.651199 | 1.929241 | 1.148337 | 1.035836 | 2.630953 | 2.580039 | 2.631611 | 3.246694 | 3.201146 |
| Jul-84 | 3.009598 | 2.374144 | 2.950005 | 2.347568 | 2.120152 | 3.362312 | 3.061371 | 3.706267 | 3.406295 | 3.19349 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Aug-84 | 2.689931 | 2.049141 | 2.434918 | 2.0161 | 2.254885 | 2.977984 | 2.450946 | 2.471442 | 2.273474 | 2.245052 |
| Sep-84 | 2.806837 | 2.677845 | 2.438498 | 1.972091 | 1.122018 | 2.541447 | 2.55113 | 3.200214 | 2.100312 | 2.317285 |
| Oct-84 | 0.132714 | 1.096774 | 1.516111 | 1.686579 | 1.605256 | 0.145968 | 1.482399 | 0.581459 | 2.029827 | 1.662109 |
| Nov-84 | 0.886265 | 1.197188 | 2.688381 | 2.983616 | 1.824708 | 0.677781 | 2.774181 | 1.480775 | 1.690345 | 1.195406 |
| Dec-84 | 0.356728 | 0.905855 | 1.951091 | 1.88923 | 1.262272 | 0.772502 | 0.506666 | 0.156119 | 0.814743 | 0.78877 |
| Jan-85 | 0.424745 | 1.38268 | 1.64987 | 1.827252 | 1.549897 | 1.492979 | 0.887988 | 1.19285 | 1.01486 | 1.012967 |
| Feb-85 | 0.674597 | 0.686693 | 1.533093 | 1.49282 | 1.038212 | 0.082437 | 0.593092 | 0.783396 | 0.380343 | 1.611181 |
| Mar-85 | 1.591059 | 1.699187 | 1.862158 | 2.135703 | 1.918809 | 1.185468 | 1.11691 | 1.199776 | 1.414393 | 1.479693 |
| Apr-85 | 0.759763 | 1.792738 | 1.882911 | 2.481768 | 2.091921 | 1.659203 | 1.652929 | 2.383654 | 1.50134 | 1.86979 |
| May-85 | 1.891772 | 2.087965 | 2.219335 | 1.816299 | 2.837782 | 1.178361 | 1.853959 | 2.058072 | 1.447985 | 2.161973 |
| Jun-85 | 2.802186 | 2.64498 | 1.515626 | 1.295956 | 1.081562 | 2.102241 | 2.34741 | 2.589176 | 2.247866 | 2.478277 |
| Jul-85 | 2.566428 | 2.124773 | 1.719843 | 1.849775 | 1.629096 | 2.599277 | 2.198995 | 2.308742 | 2.240669 | 2.621849 |
| Aug-85 | 1.792353 | 1.136113 | 1.047359 | 0.959612 | 0.62263 | 1.633975 | 1.793439 | 2.091661 | 1.889197 | 2.082709 |
| Sep-85 | 1.240669 | 0.357557 | 0.20031 | 0.327345 | 0.402345 | 1.457867 | 1.969715 | 1.982991 | 1.754741 | 2.21669 |
| Oct-85 | 0.846245 | 0.923174 | 1.112993 | 1.083213 | 1.317272 | 0.496777 | 1.269977 | 1.36423 | 1.278996 | 1.496554 |
| Nov-85 | 3.139561 | 3.625375 | 2.706231 | 2.586708 | 2.393169 | 1.732066 | 0.37936 | 1.115657 | 1.427436 | 1.565432 |
| Dec-85 | 1.344341 | 2.238446 | 1.980787 | 2.153921 | 1.914473 | 1.695604 | 1.920188 | 1.623716 | 1.45257 | 2.097142 |
| Jan-86 | 1.404006 | 1.816055 | 1.990449 | 2.053597 | 1.995328 | 1.552273 | 2.038316 | 2.236115 | 2.087547 | 2.476364 |
| Feb-86 | 2.148478 | 2.376114 | 2.82527 | 3.482489 | 2.60433 | 2.242906 | 1.620977 | 2.02564 | 1.728362 | 1.452294 |
| Mar-86 | 2.534716 | 3.034562 | 3.608758 | 3.090292 | 3.423711 | 2.778286 | 2.732533 | 2.300913 | 2.252425 | 3.257565 |
| Apr-86 | 2.416147 | 2.496501 | 2.587063 | 2.739311 | 2.151613 | 0.986685 | 1.869929 | 1.647264 | 1.836673 | 3.131326 |
| May-86 | 2.056869 | 1.68554 | 1.907868 | 2.95935 | 2.532358 | 2.654584 | 4.436661 | 3.466205 | 4.52422 | 4.68887 |
| Jun-86 | 2.079107 | 1.77704 | 1.670533 | 2.114704 | 1.734182 | 3.082839 | 3.164674 | 2.954962 | 2.356422 | 2.911973 |
| Jul-86 | 1.465866 | 0.758878 | 0.775033 | 0.78474 | 0.327963 | 1.342786 | 1.773219 | 1.867976 | 1.721427 | 2.172498 |
| Aug-86 | 2.339541 | 1.808637 | 1.747061 | 1.56716 | 1.330093 | 2.219443 | 2.213204 | 2.398861 | 2.124996 | 2.940816 |
| Sep-86 | 0.795912 | 0.136055 | 0.462024 | 0.47371 | 0.808603 | 0.816819 | 1.708645 | 1.679745 | 1.429486 | 1.972995 |
| Oct-86 | 0.861664 | 0.746188 | 0.351907 | 1.346799 | 0.79536 | 0.9069 | 1.290801 | 1.192171 | 1.175926 | 1.418238 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Nov-86 | 0.350826 | 0.938049 | 1.083649 | 1.288933 | 1.04096 | 0.371492 | 0.471972 | 0.190197 | 0.277673 | 0.371202 |
| Dec-86 | 1.035695 | 1.486669 | 1.336842 | 1.975588 | 1.265155 | 1.184462 | 1.138159 | 1.157569 | 1.86393 | 1.626033 |
| Jan-87 | 0.859554 | 1.247791 | 1.498379 | 1.633349 | 1.261174 | 1.155616 | 0.658608 | 1.600525 | 1.301261 | 1.351616 |
| Feb-87 | 1.965548 | 1.888542 | 2.250448 | 2.283347 | 2.362384 | 2.219535 | 2.326782 | 2.085958 | 3.064136 | 2.070038 |
| Mar-87 | 1.04234 | 1.6505 | 1.760684 | 2.078962 | 1.957921 | 1.917609 | 1.216787 | 1.337386 | 1.643901 | 1.32398 |
| Apr-87 | 1.498778 | 1.430464 | 2.320219 | 1.025636 | 0.864297 | 0.963395 | 0.91076 | 0.82627 | 0.360347 | 1.061695 |
| May-87 | 2.163337 | 1.506433 | 1.737532 | 0.972667 | 1.20584 | 0.892702 | 1.981638 | 2.022628 | 1.526095 | 2.076982 |
| Jun-87 | 2.117138 | 1.429336 | 1.03805 | 1.047428 | 0.858886 | 2.007641 | 2.190595 | 2.486797 | 2.311531 | 2.862547 |
| Jul-87 | 2.206907 | 1.232616 | 0.76401 | 0.936487 | 0.825223 | 2.180063 | 2.660522 | 2.691774 | 2.639171 | 2.634593 |
| Aug-87 | 1.548912 | 1.467525 | 1.698939 | 1.949353 | 1.733759 | 2.545197 | 1.897542 | 1.922528 | 1.717312 | 2.271184 |
| Sep-87 | 1.346998 | 1.247915 | 1.476134 | 0.256944 | 0.328087 | 1.050232 | 1.532741 | 1.450495 | 1.275139 | 1.764046 |
| Oct-87 | 2.467372 | 0.30959 | 1.125586 | 1.036439 | 0.337407 | 1.161157 | 1.709939 | 1.887452 | 1.472806 | 1.761303 |
| Nov-87 | 1.462746 | 0.743715 | 1.204865 | 1.51297 | 1.582514 | 1.195545 | 1.131633 | 1.487872 | 1.402025 | 1.559125 |
| Dec-87 | 2.191865 | 2.958082 | 2.810963 | 3.051948 | 2.930928 | 2.456396 | 2.395195 | 2.479922 | 2.145982 | 1.464027 |
| Jan-88 | 1.964307 | 2.407493 | 2.471632 | 2.663042 | 2.308532 | 1.848151 | 1.512121 | 1.635438 | 1.095809 | 1.12943 |
| Feb-88 | 2.294239 | 2.020674 | 2.327022 | 2.079388 | 2.018255 | 1.571413 | 1.44381 | 2.368678 | 2.298059 | 2.532185 |
| Mar-88 | 2.372202 | 2.490151 | 2.473995 | 2.392207 | 2.967775 | 2.327961 | 2.33308 | 3.516045 | 2.998991 | 3.815478 |
| Apr-88 | 1.294243 | 2.143582 | 2.277667 | 2.449671 | 2.869265 | 2.153597 | 2.610159 | 2.532468 | 2.423536 | 1.720282 |
| May-88 | 1.559961 | 2.32059 | 1.858756 | 2.607566 | 2.47131 | 2.551997 | 2.420775 | 2.625026 | 1.980137 | 2.316557 |
| Jun-88 | 2.268788 | 2.181623 | 1.810584 | 1.545946 | 1.629687 | 2.077277 | 2.574466 | 2.090163 | 2.038212 | 2.062303 |
| Jul-88 | 2.325766 | 1.877975 | 1.588375 | 1.720869 | 0.85557 | 2.380625 | 2.17484 | 3.001108 | 2.333002 | 2.294778 |
| Aug-88 | 1.879447 | 2.023009 | 2.403444 | 1.340073 | 1.286688 | 2.911612 | 2.342512 | 2.442356 | 1.878766 | 2.052874 |
| Sep-88 | 2.009026 | 1.015726 | 1.886729 | 0.921211 | 0.756902 | 1.208954 | 1.498677 | 1.82357 | 1.319376 | 1.586482 |
| Oct-88 | 1.285476 | 0.572596 | 0.25047 | 0.303866 | 0.584356 | 0.983294 | 1.238592 | 1.222402 | 0.963916 | 1.408849 |
| Nov-88 | 2.181578 | 2.987913 | 3.198314 | 3.217132 | 2.56868 | 2.097429 | 1.731534 | 1.968045 | 2.250932 | 1.629737 |
| Dec-88 | 1.115459 | 0.888493 | 1.184683 | 1.515453 | 1.151604 | 1.70479 | 1.198232 | 1.286467 | 1.418161 | 2.198863 |
| Jan-89 | 1.073746 | 1.490091 | 2.088851 | 1.940846 | 2.011594 | 2.010491 | 2.609857 | 1.59396 | 1.658582 | 1.641724 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Feb-89 | 1.971566 | 1.907954 | 2.017341 | 2.954354 | 1.544573 | 1.542771 | 1.872846 | 1.674209 | 1.706363 | 1.601061 |
| Mar-89 | 2.113725 | 2.216519 | 2.409708 | 2.4615 | 1.975265 | 1.323678 | 0.369521 | 1.014263 | 1.451527 | 0.515758 |
| Apr-89 | 0.900568 | 1.047035 | 1.42963 | 1.245154 | 1.405161 | 1.005008 | 1.116031 | 1.082182 | 1.926101 | 2.525116 |
| May-89 | 0.612101 | 1.486274 | 1.748016 | 1.72378 | 1.624452 | 0.866124 | 1.451504 | 1.743258 | 1.384625 | 1.98906 |
| Jun-89 | 2.17839 | 1.351941 | 0.871063 | 0.833295 | 0.626527 | 2.558345 | 2.792029 | 2.850768 | 2.501247 | 2.811501 |
| Jul-89 | 2.346523 | 2.135286 | 1.823965 | 1.910914 | 1.037832 | 2.27311 | 2.236708 | 2.526829 | 2.025079 | 2.221663 |
| Aug-89 | 2.470298 | 1.322566 | 1.063968 | 1.929878 | 1.668782 | 1.738735 | 2.126337 | 2.442654 | 2.296033 | 2.496812 |
| Sep-89 | 2.331033 | 1.945181 | 1.774925 | 1.82921 | 1.794097 | 2.581475 | 2.467194 | 2.406529 | 2.586699 | 2.808111 |
| Oct-89 | 1.588527 | 2.083532 | 2.393528 | 2.007498 | 1.885506 | 2.241731 | 2.455041 | 2.325193 | 2.494256 | 2.28356 |
| Nov-89 | 2.0059 | 2.060349 | 2.553353 | 2.828408 | 2.4878 | 2.719314 | 1.723155 | 1.414641 | 1.573155 | 0.986835 |
| Dec-89 | 3.202171 | 2.915833 | 2.610398 | 3.280344 | 2.779308 | 2.627521 | 2.099801 | 2.119573 | 2.994847 | 2.860146 |
| Jan-90 | 2.483496 | 2.773999 | 3.136615 | 2.567796 | 2.02511 | 2.837902 | 2.42338 | 2.897386 | 3.855265 | 3.372578 |
| Feb-90 | 2.473098 | 2.449115 | 3.381054 | 3.205872 | 3.030489 | 3.626045 | 2.896901 | 3.671987 | 3.52835 | 2.736604 |
| Mar-90 | 1.467006 | 1.751146 | 2.501944 | 2.276465 | 2.68781 | 2.306792 | 2.094134 | 1.462131 | 1.779124 | 1.632446 |
| Apr-90 | 2.25299 | 2.353128 | 2.434636 | 2.134789 | 1.638418 | 1.737578 | 1.795103 | 1.507999 | 1.147236 | 2.005562 |
| May-90 | 2.074563 | 1.62469 | 2.142181 | 1.848557 | 1.973528 | 0.757553 | 1.806538 | 0.556064 | 1.482199 | 2.027081 |
| Jun-90 | 1.358341 | 0.885517 | 0.963966 | 0.577748 | 0.438599 | 2.720851 | 1.81841 | 1.739716 | 1.643533 | 2.386349 |
| Jul-90 | 2.613824 | 1.849257 | 2.894776 | 1.449704 | 1.193914 | 2.401216 | 2.552779 | 2.854339 | 2.341433 | 2.558686 |
| Aug-90 | 1.498736 | 1.486329 | 1.440071 | 0.955377 | 0.766899 | 1.912559 | 1.846118 | 1.785493 | 1.78929 | 2.067224 |
| Sep-90 | 1.897615 | 1.119485 | 1.513863 | 1.038562 | 0.642418 | 1.537057 | 1.613874 | 1.974415 | 1.59853 | 2.393998 |
| Oct-90 | 2.91524 | 3.033474 | 2.806261 | 2.9833 | 3.218901 | 3.049754 | 2.742671 | 2.970541 | 2.903271 | 2.336876 |
| Nov-90 | 2.046808 | 2.670273 | 2.91233 | 2.894552 | 2.595486 | 2.442643 | 1.90929 | 2.953834 | 1.651108 | 1.511513 |
| Dec-90 | 1.399979 | 2.065328 | 2.673865 | 2.547963 | 2.540043 | 1.579993 | 1.610461 | 1.747625 | 1.422146 | 1.510581 |
| Jan-91 | 1.562067 | 2.180891 | 1.40174 | 1.569947 | 1.173071 | 0.442838 | 0.422997 | 0.564491 | 0.429996 | 0.646242 |
| Feb-91 | 1.240098 | 1.229514 | 0.925728 | 0.95547 | 1.197153 | 0.430249 | 0.743873 | 1.004798 | 0.44142 | 1.74308 |
| Mar-91 | 2.671088 | 3.312034 | 4.007043 | 4.085723 | 3.206563 | 2.671868 | 2.148778 | 2.905299 | 3.025525 | 2.574105 |
| Apr-91 | 2.009683 | 2.555752 | 2.90207 | 3.091616 | 2.82948 | 2.409945 | 1.735395 | 2.323994 | 1.424389 | 0.685541 |

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|---|---|---|---|---|---|---|---|---|---|---|
| May-91 | 0.320999 | 1.385131 | 1.605657 | 1.334666 | 1.41799 | 0.494537 | 1.770337 | 1.540233 | 1.578049 | 2.009188 |
| Jun-91 | 1.399129 | 0.592166 | 0.710058 | 0.778365 | 0.374989 | 1.537066 | 2.393162 | 2.171329 | 2.028207 | 2.604529 |
| Jul-91 | 1.849355 | 1.203429 | 1.057562 | 1.251596 | 0.790135 | 1.670722 | 2.038557 | 2.119611 | 1.981473 | 2.237562 |
| Aug-91 | 2.28282 | 1.799514 | 1.857985 | 1.85933 | 1.607539 | 2.336072 | 2.906029 | 2.866826 | 2.659115 | 2.946978 |
| Sep-91 | 2.219524 | 1.812554 | 1.68639 | 2.064282 | 1.55873 | 2.41765 | 2.365658 | 2.549309 | 2.120299 | 2.470952 |
| Oct-91 | 1.621422 | 1.809673 | 1.892517 | 1.760433 | 1.63911 | 1.088173 | 1.432578 | 0.808416 | 0.650001 | 1.836928 |
| Nov-91 | 2.283557 | 2.268049 | 1.899458 | 2.21826 | 1.364822 | 1.126858 | 1.07875 | 1.430598 | 1.699085 | 3.215972 |
| Dec-91 | 1.942389 | 1.406004 | 1.276073 | 2.224199 | 2.179601 | 2.642726 | 4.726418 | 3.620101 | 4.906921 | 4.887271 |
| Jan-92 | 1.501566 | 2.308281 | 2.555588 | 3.567533 | 2.994349 | 3.780074 | 3.44551 | 3.153178 | 2.311088 | 2.571785 |
| Feb-92 | 2.162361 | 2.896036 | 3.629476 | 3.498155 | 3.253125 | 2.325221 | 2.497166 | 1.907377 | 2.082338 | 0.725914 |
| Mar-92 | 2.967912 | 3.233801 | 3.131594 | 3.257677 | 2.281207 | 1.789384 | 1.151367 | 0.62872 | 0.823042 | 2.325458 |
| Apr-92 | 0.459941 | 0.480243 | 0.764998 | 1.399503 | 1.970843 | 0.761203 | 1.439936 | 2.129534 | 1.114099 | 1.635239 |
| May-92 | 1.962329 | 2.254396 | 1.406405 | 1.031154 | 2.142693 | 2.065366 | 2.485253 | 2.133616 | 2.027191 | 2.68206 |
| Jun-92 | 1.130622 | 2.438581 | 1.278721 | 1.533459 | 0.820569 | 1.35517 | 2.167268 | 1.631893 | 1.576682 | 2.123399 |
| Jul-92 | 1.621913 | 1.10425 | 1.643822 | 0.575588 | 0.708109 | 2.158248 | 2.302494 | 2.575898 | 2.015267 | 2.482596 |
| Aug-92 | 2.251191 | 1.395083 | 1.46826 | 1.207744 | 1.089762 | 2.075108 | 2.207925 | 2.443687 | 1.973444 | 2.282753 |
| Sep-92 | 1.491153 | 0.773241 | 0.948393 | 0.624025 | 1.278394 | 1.830082 | 2.133821 | 2.27472 | 2.422716 | 2.039466 |
| Oct-92 | 2.152615 | 2.518129 | 2.51975 | 2.709883 | 2.467681 | 3.614505 | 2.326881 | 2.096087 | 1.945986 | 1.571515 |
| Nov-92 | 1.502127 | 2.423334 | 3.451825 | 2.56735 | 2.257048 | 2.125676 | 1.502979 | 2.054747 | 1.477925 | 2.131192 |
| Dec-92 | 2.265693 | 2.207153 | 2.537003 | 2.213764 | 2.034115 | 1.027296 | 1.791343 | 1.837497 | 0.1667 | 1.885707 |
| Jan-93 | 1.82617 | 1.892458 | 1.815744 | 2.418127 | 2.050585 | 0.396324 | 1.415761 | 2.486694 | 2.909228 | 2.972628 |
| Feb-93 | 0.659993 | 1.245951 | 1.606501 | 1.966604 | 1.770764 | 1.362404 | 1.665667 | 1.796063 | 2.18053 | 0.771979 |
| Mar-93 | 0.311657 | 1.793899 | 2.400854 | 2.673688 | 2.355569 | 2.328708 | 0.557605 | 0.413808 | 1.125673 | 1.253854 |
| Apr-93 | 1.327004 | 1.897069 | 2.350005 | 2.025455 | 1.712436 | 0.51883 | 0.682846 | 0.292519 | 0.348592 | 0.86998 |
| May-93 | 1.693763 | 0.642765 | 0.614617 | 0.899027 | 0.829161 | 0.626149 | 1.293453 | 1.34997 | 0.939547 | 1.426779 |
| Jun-93 | 1.919865 | 0.877608 | 1.169011 | 1.666471 | 2.116473 | 1.97878 | 2.340256 | 2.981606 | 2.583153 | 3.002073 |
| Jul-93 | 1.170949 | 1.02144 | 1.175854 | 0.935079 | 1.258778 | 1.586225 | 2.347986 | 2.435682 | 2.187275 | 2.520822 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Aug-93 | 3.194102 | 3.118545 | 3.047431 | 3.041741 | 3.101347 | 3.102216 | 2.635311 | 3.22635 | 2.444108 | 2.761525 |
| Sep-93 | 3.022412 | 2.933433 | 2.146113 | 1.307286 | 1.745564 | 1.249989 | 1.712904 | 2.60868 | 1.988502 | 2.217026 |
| Oct-93 | 2.273004 | 2.170599 | 1.738577 | 1.763187 | 2.43952 | 2.295262 | 2.797889 | 4.387854 | 3.475834 | 4.660361 |
| Nov-93 | 1.644077 | 2.593712 | 2.776679 | 3.144447 | 4.613457 | 3.690992 | 4.828624 | 4.599177 | 3.868219 | 3.43248 |
| Dec-93 | 2.302105 | 3.911806 | 3.558629 | 4.452708 | 3.981897 | 3.466391 | 2.470831 | 2.808377 | 2.129145 | 2.675242 |
| Jan-94 | 2.314088 | 2.958054 | 2.775629 | 2.12085 | 1.904343 | 0.929518 | 0.907309 | 1.479063 | 1.837072 | 0.912177 |
| Feb-94 | 2.070676 | 2.071673 | 2.103281 | 2.18562 | 2.709179 | 2.774894 | 1.348837 | 0.303996 | 3.000321 | 1.881451 |
| Mar-94 | 0.836935 | 1.098246 | 1.601752 | 1.282521 | 1.547747 | 1.358078 | 0.389858 | 0.603186 | 0.467793 | 0.215654 |
| Apr-94 | 0.847639 | 2.043738 | 1.64788 | 1.422991 | 1.191155 | 0.657745 | 0.993207 | 0.636133 | 0.334463 | 1.004769 |
| May-94 | 1.744775 | 0.893139 | 0.564409 | 0.686003 | 0.376625 | 1.822465 | 2.289742 | 2.133171 | 1.873742 | 2.308717 |
| Jun-94 | 1.819962 | 1.598299 | 0.878789 | 0.842971 | 0.782528 | 1.732743 | 2.63809 | 2.438828 | 2.656721 | 2.858205 |
| Jul-94 | 2.218941 | 1.406779 | 1.077474 | 1.521615 | 1.103808 | 2.60803 | 2.584864 | 2.862636 | 2.658939 | 3.358498 |
| Aug-94 | 3.193168 | 3.111094 | 3.305076 | 3.15459 | 2.947445 | 3.314783 | 4.125085 | 3.053674 | 2.508918 | 2.688559 |
| Sep-94 | 2.942457 | 2.696473 | 2.344422 | 3.29905 | 1.699752 | 2.277872 | 2.57256 | 2.441513 | 2.308142 | 2.160565 |
| Oct-94 | 1.205865 | 1.247825 | 1.470552 | 1.500398 | 1.255258 | 1.236511 | 1.168992 | 1.514262 | 1.433858 | 1.325953 |
| Nov-94 | 1.870792 | 2.092991 | 2.568727 | 2.36452 | 2.065965 | 1.678468 | 0.463769 | 1.404399 | 2.77757 | 2.999648 |
| Dec-94 | 1.145606 | 1.187195 | 1.584548 | 1.053148 | 1.263507 | 2.44302 | 2.859308 | 3.094385 | 3.236076 | 3.609666 |
| Jan-95 | 1.704006 | 2.178472 | 3.05063 | 3.59366 | 3.369145 | 2.781458 | 2.791663 | 1.373403 | 1.245542 | 1.145431 |
| Feb-95 | 1.015835 | 1.740467 | 1.810644 | 2.102007 | 1.204515 | 0.327429 | 0.673538 | 0.77131 | 0.202311 | 0.763146 |
| Mar-95 | 0.901285 | 0.506647 | 0.819183 | 1.252187 | 1.13596 | 0.433939 | 0.899038 | 0.724965 | 0.802669 | 1.131089 |
| Apr-95 | 1.248772 | 2.109882 | 2.325264 | 2.506615 | 2.159015 | 1.249747 | 0.409659 | 0.549392 | 1.060003 | 0.725307 |
| May-95 | 0.907241 | 2.011649 | 2.558446 | 2.585949 | 2.130264 | 1.345698 | 1.574942 | 1.280387 | 1.465623 | 1.463443 |
| Jun-95 | 2.140575 | 1.357991 | 1.707047 | 1.422111 | 1.5456 | 2.235846 | 2.924938 | 2.69121 | 2.744595 | 2.834045 |
| Jul-95 | 2.388205 | 1.863713 | 1.617091 | 1.771495 | 1.239709 | 1.988883 | 2.007492 | 2.249739 | 1.949134 | 2.201031 |
| Aug-95 | 3.552975 | 3.241369 | 3.112712 | 2.761999 | 2.581932 | 3.22891 | 3.458175 | 4.240912 | 6.055805 | 4.758688 |
| Sep-95 | 2.587675 | 1.642314 | 2.845685 | 2.533864 | 2.557643 | 4.375739 | 3.957207 | 4.987005 | 4.507227 | 4.240252 |
| Oct-95 | 2.224714 | 2.368919 | 3.821593 | 3.186597 | 4.155861 | 3.864658 | 3.820171 | 3.168822 | 4.049422 | 3.711401 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Nov-95 | 3.245347 | 3.707698 | 3.669029 | 3.429519 | 2.778802 | 3.22393 | 2.717437 | 3.388189 | 0.69481 | 1.114894 |
| Dec-95 | 2.574635 | 1.743791 | 2.477449 | 2.394532 | 2.881423 | 1.01245 | 1.010071 | 0.234647 | 0.652452 | 1.437349 |
| Jan-96 | 1.82331 | 2.486518 | 2.780691 | 3.189181 | 2.24964 | 1.670319 | 1.368314 | 1.18775 | 1.209125 | 0.333779 |
| Feb-96 | 0.266878 | 0.693913 | 2.577438 | 2.002738 | 1.1099 | 0.337072 | 1.600014 | 1.874004 | 0.318052 | 0.811343 |
| Mar-96 | 1.794871 | 1.238884 | 1.612085 | 1.911557 | 1.726736 | 0.560872 | 0.319871 | 0.610407 | 0.347024 | 0.689659 |
| Apr-96 | 1.153563 | 1.51357 | 1.810959 | 1.81212 | 1.643962 | 0.768072 | 0.19998 | 1.071527 | 0.66121 | 0.992283 |
| May-96 | 0.873659 | 2.511991 | 2.913332 | 2.63772 | 2.170725 | 0.892559 | 1.291418 | 0.731497 | 0.851302 | 1.676451 |
| Jun-96 | 2.458093 | 2.047857 | 1.484697 | 1.870395 | 1.584618 | 2.813031 | 2.95192 | 3.508825 | 2.716869 | 2.757691 |
| Jul-96 | 2.45353 | 2.089662 | 1.950703 | 2.061476 | 2.02748 | 2.514719 | 2.583175 | 2.996111 | 2.497219 | 2.631324 |
| Aug-96 | 2.452987 | 2.658695 | 1.53218 | 1.324772 | 1.288898 | 1.972364 | 2.29521 | 2.297554 | 2.303547 | 2.426065 |
| Sep-96 | 1.900374 | 2.019227 | 1.506676 | 1.678696 | 0.574629 | 1.759384 | 2.135541 | 1.077148 | 1.833089 | 3.6317 |
| Oct-96 | 0.864778 | 0.515651 | 1.269333 | 1.347453 | 0.949722 | 1.148796 | 2.567862 | 2.825668 | 3.408095 | 3.562775 |
| Nov-96 | 1.018003 | 1.225098 | 1.784406 | 2.586405 | 2.805646 | 2.458106 | 2.672088 | 2.89292 | 1.370582 | 1.493992 |
| Dec-96 | 1.630742 | 3.384442 | 3.812917 | 3.641728 | 3.342521 | 1.749206 | 1.128747 | 1.786166 | 1.682191 | 0.974603 |
| Jan-97 | 1.438888 | 2.040798 | 1.451242 | 1.742573 | 1.424348 | 1.101305 | 0.385418 | 0.616414 | 0.69241 | 0.544808 |
| Feb-97 | 1.229216 | 0.575137 | 0.286045 | 0.980376 | 0.537174 | 1.334486 | 1.331375 | 1.408689 | 1.255015 | 1.335822 |
| Mar-97 | 0.543416 | 0.517998 | 0.807362 | 1.281936 | 0.88348 | 0.168101 | 0.78407 | 0.435237 | 0.341842 | 0.665886 |
| Apr-97 | 0.319786 | 1.000854 | 1.291271 | 1.728228 | 1.476525 | 0.506816 | 0.939887 | 0.812614 | 0.51231 | 1.048627 |
| May-97 | 1.898501 | 1.842825 | 1.846557 | 1.711144 | 1.593995 | 1.980432 | 2.394007 | 2.041657 | 2.015754 | 2.431547 |
| Jun-97 | 2.168165 | 1.469096 | 0.800218 | 1.218469 | 0.648114 | 2.004029 | 2.563902 | 2.349892 | 2.269894 | 2.981416 |
| Jul-97 | 2.900055 | 2.326616 | 2.376703 | 2.250452 | 1.988419 | 3.07719 | 3.877772 | 3.556638 | 3.841701 | 4.044165 |
| Aug-97 | 2.336933 | 2.179368 | 2.785721 | 4.263198 | 3.18425 | 4.479021 | 4.685628 | 4.102122 | 3.815032 | 4.914732 |
| Sep-97 | 3.487276 | 4.011954 | 4.864124 | 4.653441 | 4.259427 | 4.010997 | 4.67999 | 4.18519 | 4.697224 | 1.824285 |
| Oct-97 | 3.124393 | 1.888449 | 1.17054 | 1.798242 | 1.594219 | 2.101055 | 2.68267 | 2.214971 | 1.647963 | 1.75775 |
| Nov-97 | 0.357013 | 0.865598 | 1.221373 | 2.564326 | 2.298472 | 1.029777 | 0.743147 | 2.344809 | 1.847583 | 2.188051 |
| Dec-97 | 1.790186 | 2.376997 | 2.142481 | 2.73699 | 2.473403 | 1.421034 | 1.273665 | 1.563021 | 1.50116 | 1.261491 |
| Jan-98 | 1.040888 | 2.116792 | 2.406971 | 2.477331 | 1.980467 | 1.192084 | 0.314029 | 0.732559 | 0.93853 | 0.174714 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Feb-98 | 2.113334 | 3.292215 | 3.940453 | 3.901852 | 3.16637 | 2.399064 | 1.670101 | 2.304521 | 1.858028 | 1.539953 |
| Mar-98 | 1.699332 | 1.865998 | 2.441989 | 2.558931 | 2.104833 | 1.124102 | 0.420388 | 1.050194 | 0.731162 | 0.438311 |
| Apr-98 | 1.751756 | 2.039123 | 2.686365 | 2.373366 | 2.437264 | 2.151701 | 2.044211 | 1.809249 | 2.708599 | 1.185288 |
| May-98 | 2.924402 | 3.454446 | 3.789813 | 3.723961 | 3.136981 | 3.678591 | 1.355264 | 1.221641 | 1.569577 | 0.761778 |
| Jun-98 | 1.895742 | 2.429119 | 3.451882 | 2.157584 | 1.724258 | 1.270657 | 1.213339 | 1.273765 | 0.93704 | 1.961542 |
| Jul-98 | 3.305288 | 1.852474 | 2.080643 | 1.824046 | 1.902958 | 1.916272 | 2.775945 | 3.029224 | 2.289604 | 2.983677 |
| Aug-98 | 2.893863 | 2.464214 | 1.959575 | 2.338391 | 2.061396 | 2.217154 | 2.712772 | 4.30264 | 4.438151 | 5.000911 |
| Sep-98 | 1.980495 | 1.952492 | 1.425299 | 1.912813 | 2.655916 | 3.292436 | 3.463474 | 3.586142 | 3.610293 | 2.506378 |
| Oct-98 | 0.714203 | 2.614592 | 2.90842 | 3.258977 | 3.338031 | 3.650866 | 1.753667 | 1.625401 | 1.867927 | 2.027333 |
| Nov-98 | 1.394806 | 1.931904 | 2.420637 | 1.618844 | 1.200504 | 0.998747 | 0.920792 | 0.455734 | 0.909369 | 1.292099 |
| Dec-98 | 2.140437 | 0.83197 | 1.291368 | 1.581516 | 1.032146 | 0.821631 | 1.186624 | 1.598332 | 1.031306 | 0.973101 |
| Jan-99 | 1.505775 | 2.376918 | 2.646425 | 2.872121 | 2.192382 | 1.422636 | 0.907745 | 1.390134 | 1.287045 | 0.487688 |
| Feb-99 | 1.091756 | 2.15855 | 2.35821 | 2.273663 | 2.194243 | 1.510004 | 1.140245 | 0.920224 | 1.310936 | 0.833818 |
| Mar-99 | 1.337856 | 1.93883 | 1.825506 | 2.019007 | 1.809926 | 1.854132 | 1.609067 | 1.813681 | 1.125831 | 1.933872 |
| Apr-99 | 1.824235 | 2.465554 | 2.649981 | 2.374555 | 2.205597 | 1.258397 | 1.433134 | 2.065395 | 1.617382 | 1.63527 |
| May-99 | 1.339122 | 1.514697 | 1.595438 | 1.882235 | 1.889387 | 1.054654 | 1.575059 | 2.393525 | 1.836548 | 2.705607 |
| Jun-99 | 2.059408 | 1.642339 | 1.465717 | 1.965206 | 3.234176 | 2.851058 | 3.976059 | 4.309487 | 4.235122 | 4.129464 |
| Jul-99 | 3.176833 | 4.792237 | 3.887121 | 5.14067 | 4.860303 | 4.258689 | 4.046252 | 4.993963 | 4.187232 | 4.842725 |
| Aug-99 | 3.998296 | 4.401059 | 3.913543 | 3.669921 | 4.229783 | 3.759809 | 4.586218 | 2.269303 | 1.901541 | 1.891677 |
| Sep-99 | 4.299834 | 3.558175 | 2.562673 | 2.696771 | 1.634564 | 2.330547 | 1.979964 | 1.982895 | 2.399907 | 2.559252 |
| Oct-99 | 1.089176 | 1.947887 | 1.941436 | 1.174353 | 0.936975 | 2.171806 | 1.919065 | 2.114432 | 1.782653 | 2.223449 |
| Nov-99 | 0.556014 | 1.876187 | 0.978759 | 0.859903 | 0.739784 | 0.653179 | 1.031608 | 0.476354 | 0.465163 | 1.06776 |
| Dec-99 | 1.010873 | 1.563495 | 1.844037 | 2.271048 | 1.352286 | 1.152463 | 1.517981 | 1.275672 | 1.398312 | 0.532325 |
| Jan-00 | 0.883901 | 1.477995 | 1.999928 | 2.263695 | 1.632899 | 0.586708 | 0.272061 | 0.443731 | 0.561053 | 0.193743 |
| Feb-00 | 1.18203 | 2.231804 | 2.692925 | 3.10999 | 2.520413 | 1.93139 | 1.715645 | 1.84466 | 1.423831 | 2.239383 |
| Mar-00 | 0.979429 | 1.498294 | 1.977058 | 2.037532 | 1.680134 | 0.782436 | 0.820445 | 0.434923 | 0.355709 | 0.662002 |
| Apr-00 | 2.935497 | 3.086731 | 2.376126 | 3.79087 | 1.778674 | 1.306193 | 1.895064 | 1.137289 | 1.460582 | 1.198008 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| May-00 | 1.076049 | 1.276214 | 1.499359 | 1.595214 | 1.39668 | 0.980825 | 1.236271 | 1.424885 | 1.177637 | 1.503328 |
| Jun-00 | 2.605893 | 1.686285 | 1.505038 | 1.097095 | 1.383626 | 2.645144 | 2.859173 | 3.301754 | 4.012839 | 4.415827 |
| Jul-00 | 2.43573 | 1.977161 | 1.799618 | 1.080065 | 1.948912 | 3.915411 | 4.28396 | 4.913332 | 4.627351 | 4.992426 |
| Aug-00 | 2.374495 | 1.988965 | 3.032502 | 3.214904 | 3.596056 | 4.132504 | 4.459374 | 2.776308 | 2.515552 | 2.597684 |
| Sep-00 | 2.698501 | 2.939946 | 3.083395 | 3.378113 | 1.284752 | 1.883072 | 2.206548 | 2.037163 | 1.685652 | 2.348905 |
| Oct-00 | 3.570243 | 0.979082 | 0.752568 | 1.485945 | 1.484503 | 1.489436 | 2.311687 | 2.594385 | 2.711339 | 2.542612 |
| Nov-00 | 0.281594 | 1.140982 | 1.139824 | 1.601751 | 1.306176 | 1.103879 | 0.824946 | 0.535172 | 1.197843 | 1.124212 |
| Dec-00 | 0.103817 | 0.9632 | 1.365193 | 1.395965 | 1.004504 | 1.174804 | 0.965443 | 0.947951 | 0.463995 | 1.150545 |

# Appendix I: GT5000 and GT4000 Naturalized Streamflows

# (Head flows)

| Date | Headflows, m3/s | Nov-83 | 2.710 | Oct-86 | 5.957 |
|---|---|---|---|---|---|
| Jan-81 | 2.601 | Dec-83 | 2.543 | Nov-86 | 16.122 |
| Feb-81 | 2.018 | Jan-84 | 1.762 | Dec-86 | 11.514 |
| Mar-81 | 2.591 | Feb-84 | 1.275 | Jan-87 | 9.732 |
| Apr-81 | 1.481 | Mar-84 | 1.170 | Feb-87 | 9.432 |
| May-81 | 1.171 | Apr-84 | 0.804 | Mar-87 | 7.470 |
| Jun-81 | 1.074 | May-84 | 1.095 | Apr-87 | 3.815 |
| Jul-81 | 2.582 | Jun-84 | 1.804 | May-87 | 11.199 |
| Aug-81 | 3.054 | Jul-84 | 0.838 | Jun-87 | 13.085 |
| Sep-81 | 1.603 | Aug-84 | 32.566 | Jul-87 | 4.410 |
| Oct-81 | 1.505 | Sep-84 | 2.776 | Aug-87 | 2.956 |
| Nov-81 | 1.780 | Oct-84 | 3.484 | Sep-87 | 2.787 |
| Dec-81 | 1.975 | Nov-84 | 2.799 | Oct-87 | 2.415 |
| Jan-82 | 1.946 | Dec-84 | 2.700 | Nov-87 | 2.701 |
| Feb-82 | 1.518 | Jan-85 | 4.110 | Dec-87 | 2.794 |
| Mar-82 | 2.039 | Feb-85 | 5.866 | Jan-88 | 1.875 |
| Apr-82 | 1.116 | Mar-85 | 2.506 | Feb-88 | 1.950 |
| May-82 | 1.640 | Apr-85 | 2.023 | Mar-88 | 1.363 |
| Jun-82 | 1.128 | May-85 | 2.200 | Apr-88 | 1.359 |
| Jul-82 | 0.928 | Jun-85 | 1.907 | May-88 | 1.218 |
| Aug-82 | 1.929 | Jul-85 | 1.204 | Jun-88 | 1.017 |
| Sep-82 | 3.960 | Aug-85 | 1.190 | Jul-88 | 1.607 |
| Oct-82 | 1.610 | Sep-85 | 6.767 | Aug-88 | 1.287 |
| Nov-82 | 1.988 | Oct-85 | 4.616 | Sep-88 | 1.744 |
| Dec-82 | 2.164 | Nov-85 | 3.533 | Oct-88 | 1.493 |
| Jan-83 | 2.795 | Dec-85 | 3.019 | Nov-88 | 1.706 |
| Feb-83 | 2.574 | Jan-86 | 2.204 | Dec-88 | 1.728 |
| Mar-83 | 2.176 | Feb-86 | 1.670 | Jan-89 | 2.036 |
| Apr-83 | 1.774 | Mar-86 | 1.356 | Feb-89 | 2.265 |
| May-83 | 1.084 | Apr-86 | 0.906 | Mar-89 | 1.619 |
| Jun-83 | 1.001 | May-86 | 0.773 | Apr-89 | 1.204 |
| Jul-83 | 1.007 | Jun-86 | 68.752 | May-89 | 0.920 |
| Aug-83 | 0.909 | Jul-86 | 15.692 | Jun-89 | 0.746 |
| Sep-83 | 1.731 | Aug-86 | 2.447 | Jul-89 | 0.715 |
| Oct-83 | 2.946 | Sep-86 | 3.527 | Aug-89 | 1.015 |

| | | | | | |
|---|---|---|---|---|---|
| Sep-89 | 1.043 | Nov-92 | 2.694 | Jan-96 | 2.519 |
| Oct-89 | 1.077 | Dec-92 | 2.324 | Feb-96 | 2.034 |
| Nov-89 | 1.681 | Jan-93 | 2.831 | Mar-96 | 1.719 |
| Dec-89 | 1.867 | Feb-93 | 2.428 | Apr-96 | 1.715 |
| Jan-90 | 2.335 | Mar-93 | 1.378 | May-96 | 3.364 |
| Feb-90 | 2.163 | Apr-93 | 1.414 | Jun-96 | 3.905 |
| Mar-90 | 1.658 | May-93 | 1.247 | Jul-96 | 5.304 |
| Apr-90 | 1.169 | Jun-93 | 1.161 | Aug-96 | 3.299 |
| May-90 | 0.619 | Jul-93 | 4.761 | Sep-96 | 4.094 |
| Jun-90 | 0.174 | Aug-93 | 1.448 | Oct-96 | 2.257 |
| Jul-90 | 0.919 | Sep-93 | 1.634 | Nov-96 | 6.529 |
| Aug-90 | 1.868 | Oct-93 | 5.826 | Dec-96 | 2.620 |
| Sep-90 | 3.085 | Nov-93 | 2.070 | Jan-97 | 2.039 |
| Oct-90 | 3.419 | Dec-93 | 2.262 | Feb-97 | 1.959 |
| Nov-90 | 4.052 | Jan-94 | 1.809 | Mar-97 | 1.557 |
| Dec-90 | 2.597 | Feb-94 | 2.478 | Apr-97 | 1.522 |
| Jan-91 | 2.461 | Mar-94 | 1.479 | May-97 | 1.594 |
| Feb-91 | 2.185 | Apr-94 | 1.251 | Jun-97 | 2.126 |
| Mar-91 | 1.286 | May-94 | 2.342 | Jul-97 | 4.434 |
| Apr-91 | 0.656 | Jun-94 | 1.336 | Aug-97 | 1.860 |
| May-91 | 0.390 | Jul-94 | 2.596 | Sep-97 | 1.744 |
| Jun-91 | 0.751 | Aug-94 | 1.365 | Oct-97 | 6.837 |
| Jul-91 | 2.073 | Sep-94 | 1.542 | Nov-97 | 15.176 |
| Aug-91 | 1.340 | Oct-94 | 7.944 | Dec-97 | 3.570 |
| Sep-91 | 14.100 | Nov-94 | 2.640 | Jan-98 | 3.095 |
| Oct-91 | 6.244 | Dec-94 | 2.055 | Feb-98 | 2.581 |
| Nov-91 | 7.723 | Jan-95 | 3.375 | Mar-98 | 2.053 |
| Dec-91 | 20.306 | Feb-95 | 3.011 | Apr-98 | 1.734 |
| Jan-92 | 2.315 | Mar-95 | 2.587 | May-98 | 1.225 |
| Feb-92 | 3.673 | Apr-95 | 1.332 | Jun-98 | 0.953 |
| Mar-92 | 2.508 | May-95 | 1.641 | Jul-98 | 3.318 |
| Apr-92 | 2.146 | Jun-95 | 1.832 | Aug-98 | 1.602 |
| May-92 | 6.613 | Jul-95 | 7.149 | Sep-98 | 1.368 |
| Jun-92 | 16.472 | Aug-95 | 1.966 | Oct-98 | 3.722 |
| Jul-92 | 4.719 | Sep-95 | 3.170 | Nov-98 | 7.414 |
| Aug-92 | 2.490 | Oct-95 | 7.270 | Dec-98 | 1.873 |
| Sep-92 | 2.292 | Nov-95 | 3.313 | Jan-99 | 1.561 |
| Oct-92 | 5.498 | Dec-95 | 3.152 | Feb-99 | 1.568 |

| | |
|---|---|
| Mar-99 | 1.523 |
| Apr-99 | 1.574 |
| May-99 | 1.523 |
| Jun-99 | 10.422 |
| Jul-99 | 6.273 |
| Aug-99 | 1.692 |
| Sep-99 | 1.815 |
| Oct-99 | 5.717 |
| Nov-99 | 2.316 |
| Dec-99 | 1.679 |
| Jan-00 | 1.997 |
| Feb-00 | 2.069 |
| Mar-00 | 1.915 |
| Apr-00 | 1.453 |
| May-00 | 1.338 |
| Jun-00 | 2.138 |
| Jul-00 | 5.552 |
| Aug-00 | 1.734 |
| Sep-00 | 1.432 |
| Oct-00 | 5.733 |
| Nov-00 | 5.377 |
| Dec-00 | 2.666 |

## Appendix J: 10- Year Monthly Results for Calibration Period

| | Upper Basin | | Entire Basin | |
|---|---|---|---|---|
| Date | Naturalized Streamflows, m3 | Simulated Streamflows, m3 | Naturalized Streamflows, m3 | Simulated Streamflows, m3 |
| Jan-81 | 7517925 | 3729914 | 19372937 | 18562725 |
| Feb-81 | 2306801 | 2624926 | 12850931 | 15895552 |
| Mar-81 | 5127948 | 3718913 | 15357350 | 18642205 |
| Apr-81 | 6594618 | 2100234 | 66660196 | 32984921 |
| May-81 | 2571881 | 1747921 | 56637633 | 45248507 |
| Jun-81 | 0 | 0 | 28374884 | 29934044 |
| Jul-81 | 1026637 | 3857837 | 19786592 | 24192947 |
| Aug-81 | 5876413 | 4612077 | 29057404 | 25702247 |
| Sep-81 | 4377924 | 2557259 | 18675725 | 22573580 |
| Oct-81 | 6596778 | 2793462 | 107250911 | 46567469 |
| Nov-81 | 5554632 | 2482015 | 25751266 | 28953654 |
| Dec-81 | 6427510 | 2832147 | 23396202 | 17797396 |
| Jan-82 | 4789547 | 2829985 | 20959327 | 16329842 |
| Feb-82 | 2583964 | 1991611 | 17937258 | 14630217 |
| Mar-82 | 4706736 | 2936380 | 19270746 | 12775817 |
| Apr-82 | 0 | 0 | 13678174 | 12547978 |
| May-82 | 4236446 | 2604565 | 32567409 | 17428300 |
| Jun-82 | 2075824 | 1944184 | 16168412 | 14703924 |
| Jul-82 | 0 | 0 | 12611199 | 12159358 |
| Aug-82 | 4034987 | 2862889 | 13555215 | 11551563 |
| Sep-82 | 4898292 | 5529957 | 12720228 | 12768340 |
| Oct-82 | 3065665 | 2337878 | 11863099 | 9722655 |
| Nov-82 | 3997147 | 2814921 | 13682858 | 8589340 |
| Dec-82 | 4132229 | 3316180 | 15487533 | 9015090 |
| Jan-83 | 5598778 | 4308323 | 16257147 | 10958449 |
| Feb-83 | 4496671 | 3481462 | 14815375 | 10670300 |
| Mar-83 | 4508378 | 3208377 | 14890760 | 10097702 |
| Apr-83 | 0 | 0 | 9575084 | 8414072 |
| May-83 | 699100 | 1620467 | 8878135 | 7967118 |
| Jun-83 | 847158 | 1459218 | 10711109 | 7192216 |
| Jul-83 | 307241 | 1506087 | 7426300 | 6668089 |

| | | | | |
|---|---|---|---|---|
| Aug-83 | 1717885 | 1351817 | 7583663 | 6121901 |
| Sep-83 | 714449 | 2470442 | 6543887 | 6930933 |
| Oct-83 | 6398791 | 5030190 | 33503011 | 15695170 |
| Nov-83 | 5025259 | 4061848 | 19582768 | 16135216 |
| Dec-83 | 4263183 | 3694332 | 15852138 | 10950583 |
| Jan-84 | 3793801 | 2616190 | 15670454 | 11215709 |
| Feb-84 | 2513184 | 1692891 | 12536989 | 9315078 |
| Mar-84 | 1996740 | 1725818 | 11707095 | 8287089 |
| Apr-84 | 1566108 | 1163023 | 9759932 | 6394974 |
| May-84 | 2938692 | 1711642 | 9630884 | 7208351 |
| Jun-84 | 6290488 | 6672580 | 10878312 | 10205116 |
| Jul-84 | 1906989 | 1652531 | 9083521 | 7110937 |
| Aug-84 | 37563631 | 46646623 | 32457154 | 33031874 |
| Sep-84 | 1808579 | 4021965 | 8314624 | 10650341 |
| Oct-84 | 4964578 | 6030968 | 16304683 | 20306376 |
| Nov-84 | 3896248 | 5375225 | 12062334 | 20197511 |
| Dec-84 | 4129236 | 5979067 | 14776806 | 18155325 |
| Jan-85 | 7826417 | 7386085 | 18387480 | 19330556 |
| Feb-85 | 7763324 | 8462149 | 15196480 | 19932589 |
| Mar-85 | 2788769 | 4026301 | 11848599 | 16944695 |
| Apr-85 | 0 | 0 | 9367817 | 14710041 |
| May-85 | 2109854 | 3385819 | 8917276 | 15501153 |
| Jun-85 | 0 | 0 | 10468096 | 15670291 |
| Jul-85 | 298910 | 2191476 | 9250428 | 15293314 |
| Aug-85 | 1801830 | 1916799 | 9453486 | 14547378 |
| Sep-85 | 2860248 | 10044229 | 12977712 | 29392696 |
| Oct-85 | 8012941 | 7682675 | 20965460 | 34828138 |
| Nov-85 | 5126527 | 5183027 | 15878149 | 23999528 |
| Dec-85 | 4804675 | 4424945 | 14238180 | 14878166 |
| Jan-86 | 4415826 | 3306840 | 13450662 | 12647690 |
| Feb-86 | 3463134 | 2324097 | 11355892 | 10995080 |
| Mar-86 | 0 | 0 | 8928771 | 9259031 |
| Apr-86 | 2900061 | 1404647 | 9646527 | 8295309 |
| May-86 | 2290167 | 1458494 | 51493809 | 12164044 |
| Jun-86 | 76048728 | 96765865 | 68379918 | 70256689 |
| Jul-86 | 17223648 | 23094308 | 21018747 | 24895675 |
| Aug-86 | 3479979 | 4789853 | 26368279 | 22162188 |
| Sep-86 | 7345832 | 6743761 | 23877226 | 27686392 |

| | | | | |
|---|---|---|---|---|
| Oct-86 | 10555621 | 12868119 | 98242300 | 65727352 |
| Nov-86 | 19741094 | 25233364 | 42542438 | 56341579 |
| Dec-86 | 17477931 | 28631234 | 34623776 | 61957584 |
| Jan-87 | 15375211 | 14656511 | 32121028 | 38245047 |
| Feb-87 | 9973700 | 15591002 | 26961702 | 46911400 |
| Mar-87 | 15783139 | 12442258 | 28870462 | 40633732 |
| Apr-87 | 3819461 | 7573588 | 15946701 | 39145238 |
| May-87 | 7030435 | 21136158 | 16160250 | 69208336 |
| Jun-87 | 39596293 | 21532853 | 32673778 | 59654148 |
| Jul-87 | 25978550 | 7137033 | 36508825 | 34594836 |
| Aug-87 | 7616891 | 6010360 | 26854900 | 36335868 |
| Sep-87 | 9102574 | 4866816 | 24064945 | 44540958 |
| Oct-87 | 5029528 | 3943522 | 16183192 | 35615763 |
| Nov-87 | 5903835 | 4075717 | 17561077 | 21925575 |
| Dec-87 | 6671120 | 4403697 | 17689070 | 16741666 |
| Jan-88 | 6254868 | 3003299 | 16733231 | 13225665 |
| Feb-88 | 5941619 | 2878480 | 15605832 | 11567492 |
| Mar-88 | 4169659 | 2311089 | 13503064 | 9639903 |
| Apr-88 | 1406386 | 2263680 | 9786360 | 8627000 |
| May-88 | 5641310 | 2230063 | 16912002 | 11007887 |
| Jun-88 | 4366755 | 1842448 | 11103622 | 8807783 |
| Jul-88 | 5421990 | 3273917 | 18971306 | 13027247 |
| Aug-88 | 3676766 | 2537317 | 12266593 | 12035317 |
| Sep-88 | 5231724 | 3094523 | 52850137 | 23955025 |
| Oct-88 | 3020770 | 2526291 | 19535847 | 21358614 |
| Nov-88 | 3868646 | 2759801 | 15483479 | 13250764 |
| Dec-88 | 4048906 | 2886397 | 15809327 | 9290728 |
| Jan-89 | 5026776 | 3323866 | 15958786 | 9212768 |
| Feb-89 | 4954023 | 3362720 | 16187771 | 11653564 |
| Mar-89 | 13177 | 2740375 | 13120084 | 11579233 |
| Apr-89 | 1475983 | 2075377 | 12910332 | 9687218 |
| May-89 | 5450774 | 1763374 | 12665671 | 9795505 |
| Jun-89 | 2134196 | 1496916 | 10276285 | 7894312 |
| Jul-89 | 112914 | 1478229 | 6996318 | 6585611 |
| Aug-89 | 3810119 | 2138340 | 8662814 | 6962604 |
| Sep-89 | 4631743 | 2094951 | 9095650 | 8362469 |
| Oct-89 | 3567546 | 2003877 | 10765563 | 8528489 |
| Nov-89 | 4257269 | 2773749 | 11558874 | 7153815 |

| | | | | |
|---|---|---|---|---|
| Dec-89 | 4227560 | 3125896 | 12331626 | 5562407 |
| Jan-90 | 5986974 | 3783605 | 13379892 | 5663938 |
| Feb-90 | 4107421 | 3248326 | 11104585 | 5613080 |
| Mar-90 | 740724 | 2851260 | 9209655 | 6079419 |
| Apr-90 | 3292694 | 2103356 | 11089991 | 7041282 |
| May-90 | 3714392 | 1363865 | 33476224 | 8932356 |
| Jun-90 | 0 | 0 | 9037674 | 5778712 |
| Jul-90 | 4211734 | 2428025 | 61790952 | 11140668 |
| Aug-90 | 8166060 | 4401143 | 25488351 | 15440289 |
| Sep-90 | 9075402 | 7374423 | 35605828 | 38007558 |
| Oct-90 | 8114820 | 6405339 | 33485371 | 40831717 |
| Nov-90 | 9582703 | 6399710 | 22526411 | 29691233 |
| Dec-90 | 6121086 | 4429755 | 18747714 | 18790110 |

# Appendix K: Annual Results for Calibration Period

| Year | Upper Basin | | Entire Basin | |
|---|---|---|---|---|
| | Naturalized Streamflows, m3 | Simulated Streamflows, m3 | Naturalized Streamflows, m3 | Simulated Streamflows, m3 |
| 1981 | 53979069 | 34611636 | 423172031 | 327055245 |
| 1982 | 38520838 | 32435270 | 200501458 | 152222423 |
| 1983 | 34576894 | 34713807 | 165619380 | 117801749 |
| 1984 | 73368273 | 85288522 | 163182788 | 162078680 |
| 1985 | 43393494 | 60816804 | 156949163 | 235028545 |
| 1986 | 164942020 | 208695382 | 409928346 | 382388613 |
| 1987 | 151880738 | 123369515 | 291595930 | 483552567 |
| 1988 | 53049399 | 31607305 | 218560799 | 155793426 |
| 1989 | 39662080 | 28377669 | 140529774 | 102977995 |
| 1990 | 63114011 | 45502840 | 284942647 | 193010361 |

# Appendix L: Monthly Results for Calibration Period

| Month | Upper Basin | | Entire Basin | |
|---|---|---|---|---|
| | Naturalized Streamflows, m3 | Simulated Streamflows, m3 | Naturalized Streamflows, m3 | Simulated Streamflows, m3 |
| January | 6658612 | 4894462 | 18229095 | 15539239 |
| February | 4810384 | 4565766 | 15455281 | 15718435 |
| March | 3983527 | 3803557 | 14670658 | 14393882 |
| April | 2105531 | 2586214 | 16842111 | 14784803 |
| May | 3668305 | 3902237 | 24733929 | 20446156 |
| June | 13135944 | 13707235 | 20807209 | 23009723 |
| July | 5648861 | 4825315 | 20344419 | 15566868 |
| August | 7774456 | 7726722 | 19174786 | 18389123 |
| September | 5004677 | 4879833 | 20472596 | 22486829 |
| October | 5932704 | 5162232 | 36809944 | 29918174 |
| November | 6695336 | 6115938 | 19662965 | 22623821 |
| December | 6230344 | 6372365 | 18295237 | 18313906 |

# Appendix M: 10- Year Monthly Results for Validation Period

| | Upper Basin | | Entire Basin | |
|---|---|---|---|---|
| Date | Naturalized Streamflows, m3 | Simulated Streamflows, m3 | Naturalized Streamflows, m3 | Simulated Streamflows, m3 |
| Jan-91 | 6126048 | 3530050 | 18014326 | 20099583 |
| Feb-91 | 4960509 | 2842719 | 15276521 | 16596796 |
| Mar-91 | 4207178 | 1862909 | 15082557 | 13674235 |
| Apr-91 | 2203394 | 937500 | 11476869 | 13390433 |
| May-91 | 1123779 | 587269 | 8811875 | 13264396 |
| Jun-91 | 1323493 | 1069983 | 8218574 | 12873576 |
| Jul-91 | 4437757 | 3280835 | 10880918 | 20096099 |
| Aug-91 | 0 | 0 | 9213628 | 25006113 |
| Sep-91 | 20243566 | 20336811 | 67775652 | 59717734 |
| Oct-91 | 9323701 | 8931147 | 27670330 | 40787245 |
| Nov-91 | 11551828 | 10778106 | 22012449 | 29973736 |
| Dec-91 | 25416188 | 29638420 | 31373073 | 44228399 |
| Jan-92 | 8547757 | 4485897 | 19374588 | 30923235 |
| Feb-92 | 7304151 | 6871147 | 24364872 | 39238979 |
| Mar-92 | 3342208 | 3858614 | 18468728 | 32197168 |
| Apr-92 | 981493 | 3194487 | 14795851 | 32180159 |
| May-92 | 14252883 | 16199971 | 47132012 | 76706188 |
| Jun-92 | 24977745 | 25747136 | 43117519 | 62867339 |
| Jul-92 | 7077076 | 8355704 | 42647019 | 51796709 |
| Aug-92 | 2768567 | 4487837 | 17973420 | 47341237 |
| Sep-92 | 3369175 | 3578977 | 15296934 | 37257760 |
| Oct-92 | 7622755 | 7907336 | 18822362 | 30513452 |
| Nov-92 | 4347106 | 3863215 | 16458632 | 18305352 |
| Dec-92 | 4895569 | 3443437 | 17989344 | 13107023 |
| Jan-93 | 6326340 | 4296506 | 16915846 | 13624001 |
| Feb-93 | 5458709 | 3273284 | 14622158 | 12144073 |
| Mar-93 | 0 | 0 | 10780939 | 10549823 |
| Apr-93 | 0 | 0 | 9190538 | 10435493 |
| May-93 | 957991 | 1952635 | 9250413 | 12260160 |
| Jun-93 | 1043303 | 1766880 | 9663212 | 9983852 |
| Jul-93 | 1472712 | 7962109 | 7479087 | 14573588 |

| | | | | |
|---|---|---|---|---|
| Aug-93 | 0 | 0 | 6155550 | 13787010 |
| Sep-93 | 905561 | 2385942 | 16245918 | 17774458 |
| Oct-93 | 7932445 | 8418850 | 12659807 | 19044855 |
| Nov-93 | 5709967 | 2945097 | 13177281 | 9898623 |
| Dec-93 | 5609507 | 3324540 | 13319600 | 7663411 |
| Jan-94 | 5571820 | 2684346 | 12789017 | 9853797 |
| Feb-94 | 5476120 | 3287227 | 12128449 | 9767016 |
| Mar-94 | 4029092 | 2222665 | 11697251 | 8614161 |
| Apr-94 | 0 | 0 | 5554104 | 8536728 |
| May-94 | 3594435 | 3795327 | 10118631 | 12016576 |
| Jun-94 | 1112252 | 2021110 | 4788358 | 7546784 |
| Jul-94 | 1336502 | 3853095 | 7590059 | 8871765 |
| Aug-94 | 0 | 0 | 5004310 | 7172837 |
| Sep-94 | 2814334 | 2284035 | 8351440 | 9504820 |
| Oct-94 | 11066137 | 11438544 | 14123565 | 16432627 |
| Nov-94 | 4909512 | 3757633 | 9883880 | 10527407 |
| Dec-94 | 4817760 | 3063045 | 10306995 | 8302458 |
| Jan-95 | 5607175 | 4936011 | 11201043 | 8911730 |
| Feb-95 | 4474829 | 3999965 | 9338890 | 8306533 |
| Mar-95 | 5303442 | 3809891 | 10667640 | 8748801 |
| Apr-95 | 0 | 0 | 8318769 | 9725149 |
| May-95 | 513734 | 2533339 | 11200473 | 19807031 |
| Jun-95 | 1743454 | 2828716 | 13101612 | 15637728 |
| Jul-95 | 8097765 | 10325035 | 10873712 | 17132449 |
| Aug-95 | 1944882 | 2952058 | 6817040 | 11100921 |
| Sep-95 | 4932912 | 4902231 | 9745144 | 16313861 |
| Oct-95 | 10302238 | 10528148 | 13150498 | 18950151 |
| Nov-95 | 5534643 | 4700384 | 10217049 | 12552741 |
| Dec-95 | 6001972 | 4643480 | 12341302 | 9607069 |
| Jan-96 | 5483030 | 3732273 | 11067379 | 8181667 |
| Feb-96 | 4216811 | 2752505 | 9057055 | 6822120 |
| Mar-96 | 4050432 | 2590593 | 10490893 | 6069174 |
| Apr-96 | 3115110 | 2526830 | 11941581 | 6386898 |
| May-96 | 0 | 0 | 44384901 | 8670996 |
| Jun-96 | 3749168 | 5572744 | 17588408 | 8231210 |
| Jul-96 | 3186173 | 7785442 | 6807546 | 9588812 |
| Aug-96 | 4570097 | 5136255 | 21925356 | 14201586 |
| Sep-96 | 7996758 | 6472483 | 76360625 | 31509172 |

| | | | | |
|---|---|---|---|---|
| Oct-96 | 3811706 | 3413375 | 21338876 | 26548931 |
| Nov-96 | 8871852 | 9232507 | 20095668 | 28236101 |
| Dec-96 | 5271302 | 3905006 | 17279096 | 16108940 |
| Jan-97 | 5104954 | 3094877 | 15981071 | 14370776 |
| Feb-97 | 4261206 | 2796354 | 30171428 | 16507179 |
| Mar-97 | 2733967 | 2427458 | 23627878 | 17041825 |
| Apr-97 | 0 | 0 | 14453945 | 21868261 |
| May-97 | 713163 | 2740193 | 15025401 | 23439495 |
| Jun-97 | 4614433 | 3437911 | 58191152 | 21914592 |
| Jul-97 | 925816 | 6743441 | 12490956 | 18421253 |
| Aug-97 | 4087173 | 3024290 | 13871910 | 16058724 |
| Sep-97 | 2938906 | 2728953 | 11214183 | 17113191 |
| Oct-97 | 7807435 | 10009360 | 14365642 | 19521605 |
| Nov-97 | 16882165 | 21153256 | 20430421 | 22471667 |
| Dec-97 | 5243088 | 5422723 | 12737188 | 12039038 |
| Jan-98 | 5035339 | 4643829 | 12701613 | 11327029 |
| Feb-98 | 4422841 | 3556581 | 10961384 | 10073823 |
| Mar-98 | 3412074 | 3167847 | 11338995 | 10547689 |
| Apr-98 | 0 | 0 | 7062622 | 8748434 |
| May-98 | 0 | 0 | 5041820 | 7600169 |
| Jun-98 | 3458916 | 1547123 | 7206106 | 5567386 |
| Jul-98 | 0 | 0 | 3418247 | 6905124 |
| Aug-98 | 0 | 0 | 46024273 | 10004803 |
| Sep-98 | 3136752 | 2142347 | 18783582 | 11121383 |
| Oct-98 | 5515076 | 5664080 | 13779074 | 14357277 |
| Nov-98 | 11115537 | 10500783 | 19052876 | 17867013 |
| Dec-98 | 4323934 | 2965100 | 12881465 | 10740733 |
| Jan-99 | 4358821 | 2487211 | 12483412 | 9569582 |
| Feb-99 | 3096479 | 2273314 | 9672545 | 8233194 |
| Mar-99 | 4824188 | 2454961 | 12563028 | 10117632 |
| Apr-99 | 1013400 | 2438248 | 9267180 | 10335130 |
| May-99 | 1172877 | 2474068 | 9337822 | 11197296 |
| Jun-99 | 15070896 | 14707751 | 22881265 | 19259910 |
| Jul-99 | 8104896 | 9747160 | 12397114 | 15042418 |
| Aug-99 | 2009011 | 2743377 | 6633065 | 8825360 |
| Sep-99 | 2016664 | 2801553 | 6191010 | 8827313 |
| Oct-99 | 4459439 | 8427192 | 8431995 | 11507087 |
| Nov-99 | 4357775 | 3480748 | 9070618 | 6300445 |

| | | | | |
|---|---|---|---|---|
| Dec-99 | 5052089 | 2678632 | 10386502 | 4332081 |
| Jan-00 | 4586129 | 3135402 | 10529737 | 4531460 |
| Feb-00 | 4525067 | 2950107 | 10049005 | 4331267 |
| Mar-00 | 8867178 | 3024551 | 11423921 | 4575284 |
| Apr-00 | 0 | 0 | 7170914 | 4163534 |
| May-00 | 0 | 0 | 4559640 | 4011150 |
| Jun-00 | 1635334 | 4311203 | 37170802 | 7777628 |
| Jul-00 | 3953200 | 8244021 | 15201855 | 10331358 |
| Aug-00 | 0 | 0 | 5949407 | 5540083 |
| Sep-00 | 548678 | 2273431 | 5851391 | 5037049 |
| Oct-00 | 13960547 | 8618378 | 24312094 | 14233777 |
| Nov-00 | 14870857 | 7814413 | 31575032 | 16854673 |
| Dec-00 | 6512784 | 4135909 | 18673742 | 11130682 |

# Appendix N: Annual Results for Validation Period

| Year | Upper Basin | | Entire Basin | |
|---|---|---|---|---|
| | Naturalized Streamflows, m3 | Simulated Streamflows, m3 | Naturalized Streamflows, m3 | Simulated Streamflows, m3 |
| 1991 | 90917443 | 85955911 | 245806769 | 309708344 |
| 1992 | 89486485 | 91993757 | 296441280 | 472434601 |
| 1993 | 35416537 | 42946890 | 139460349 | 151739348 |
| 1994 | 44727965 | 42311471 | 112336058 | 117146974 |
| 1995 | 54457046 | 58132823 | 126973174 | 156794164 |
| 1996 | 54322439 | 58050795 | 268337384 | 170555606 |
| 1997 | 55312305 | 66037859 | 242561175 | 220767606 |
| 1998 | 40420468 | 46344233 | 168252059 | 124860862 |
| 1999 | 55536535 | 56714217 | 129315555 | 123547449 |
| 2000 | 59459775 | 51770270 | 182467540 | 92517946 |

# Appendix O: Monthly Results for Validation Period

| Month | Upper Basin | | Entire Basin | |
|---|---|---|---|---|
| | Naturalized Streamflows, m3 | Simulated Streamflows, m3 | Naturalized Streamflows, m3 | Simulated Streamflows, m3 |
| January | 5674741 | 3702640 | 14105803 | 13139286 |
| February | 4819672 | 3460320 | 14564231 | 13202098 |
| March | 4076976 | 2750175 | 13614183 | 12213579 |
| April | 731340 | 2233642 | 9923237 | 12577022 |
| May | 2232886 | 3939001 | 16486299 | 18897346 |
| June | 5872900 | 6301056 | 22192701 | 17166001 |
| July | 3859190 | 7127881 | 12978651 | 17275957 |
| August | 1537973 | 3040147 | 13956796 | 15903867 |
| September | 4890331 | 4990676 | 23581588 | 21417674 |
| October | 8180148 | 8335641 | 16865424 | 21189701 |
| November | 8815124 | 7822614 | 17197391 | 17298776 |
| December | 7314419 | 6322029 | 15728831 | 13725984 |

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# Vita

Sedat Yalcinkaya was born in Istanbul, Turkey. He completed his middle school education at Eyup Anatolian Religious High School in 1999. Mr. Yalcinkaya studied religion and Arabic besides modern sciences and English at his early age. Education, social network and vision he had at the middle school have helped him throughout his life. After completing his high school education at Beylerbeyi Haci Sabanci Anatolian High School, he started his undergraduate studies in Environmental Engineering at Yildiz Technical University in Istanbul, Turkey. Mr. Sedat Yalcinkaya received his Bachelor of Science degree from Yildiz Technical University on June, 2007, graduating as the second best graduate out of sixty from the environmental engineering department of the year. After completing his engineering education, he started to work for the Solid Waste Management Department of Istanbul Metropolitan Municipality and he started his Master of Science education in Environmental Engineering at Yildiz Technical University. Mr. Yalcinkaya worked as an environmental engineer responsible from Turkey's first biogas plant project with a budget of 4.5 million Euros. After one year professional work and completing the first semester of his master's education, He decided to move to the US for higher education on a scholarship program supported by Turkish Government in 2008. He studied English in English Language Institute at the University of Delaware between 2008 and 2009. The author started his Master of Science degree in Environmental and Water Resources Engineering Department at University of Texas at Austin on August 2009 and has been studying on water resources planning and management for two years.

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